Academic Biologists' Conceptions of Biology Education

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A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of

Doctor of Philosophy

in the Graduate Academic Unit of Education

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This dissertation is accepted by the
Dean of Graduate Studies

THE UNIVERSITY OF NEW BRUNSWICK

October, 2015

ABSTRACT

This study explored the variation in academic biologists' conceptions of biology education. Rather than being based on a hypothesis or prediction, the study's starting point was the self-reflection of a biologist/biology teacher/science educator who was interested in placing her own experiences with biology education within the realm of biologists who teach and carry out research at universities.

The study followed a phenomenographic approach designed to map the terrain of academic biologists' understanding of the phenomenon of biology education. Data were acquired through semi-structured interviews with eleven academic biologists from seven universities in Canada.

The study's outcome space is inclusive of six categories of description. Three categories express an understanding of biology teaching:

- biology teaching is bound by the discipline-based curriculum/syllabus and related pedagogy;
- biology teaching varies within levels of the education system;
- biology teaching is an extension of academic biologist's own experiences with biology as a study subject, as a science discipline and as a career.

Three categories express an understanding of biology learning:

- biology learning results from doing biology through preferred process and place;
- biology learning is related to the person who guides or mentors the student;
- biology learning is multiple discovery related to circumstance and opportunity.

The outcome space has implications for the secondary biology curriculum from the perspective of curriculum development, school biology teachers and academic biologists themselves.

DEDICATION

My husband Ken was as much a participant in the journey to complete this dissertation as I was so I dedicate this document to him with recognition and love. Words are insufficient to express my gratitude for his ceaseless patience and sage advice.

ACKNOWLEDGEMENTS

I greatly appreciate the guidance given to me during my PhD program by my advisor Dr. Alan Sears and by the members of my supervisory committee, Dr. Susan Barker and Dr. R. Steven Turner. Dr. Karen Sullenger's contributions were also valuable to me.

I am obliged to the Education Faculty at the University of New Brunswick for its generous and accommodating support of my doctoral work.

I acknowledge, with thanks, the funding that the Natural Sciences and Engineering Research Council provided for my graduate program through the Centers for Research in Youth Science Teaching and Learning, specifically CRYSTAL Atlantique. I also acknowledge, with gratitude, the grant that I was given by the New Brunswick Teachers Association in support of my studies.

I am grateful to the Department of Secondary Education at the University of Alberta for inviting me to spend an academic term there, in 2008, as a visiting scholar.

I am also grateful to the New Brunswick Department of Education for providing me with paper copies of the province's secondary biology curriculum documents to use in my research interviews.

I recognize with respect and indebtedness, the willingness with which my study participants shared their conceptions and experiences with me.

Finally, I commend Dr. Joan Chamber's for her faith in my work. She provided encouragement and constructive advice when I needed it most.

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Chapter 1 Introduction

> Of course no one has asked a broad and extensive cross section of biologists how they see the world. An individual's sense of the common vision is a result of years of contact with other people who have claimed to be biologists, who have made life decisions to become biologists, or who are biologists without decision to become biologists, or who are biologists without knowing it. (Janovy, 1985, p. 12)

Background

I was taught the science of biology in various ways by various individuals in various situations and through various means. I learned the science of biology in various ways as well and then I started to do biology and to teach it to others.

Upon reflection, I find that I have distinctly interrelated conceptions of what biology teaching and learning is all about. What I do as a biologist is related to what I have learned about biology through formal education and as a result of my work as a field botanist. What I teach students about biology and what I expect them to know about biology is linked with my understanding of what biology is and of what biologists do. How biology was taught to me affects what I perceive of biology as a discipline of study and instruction. How I teach biology differs significantly from the approach used by my own school biology teachers (who were trained in a different era) and definitely from the approach used by my own university biology professors (who had no formalized teacher training at all). What biology is as a discipline influences my opinions of what a biology curriculum should include.

Round and round my mind goes when I attempt to frame a personal conception of biology teaching and learning. There are fuzzy borders that I have difficulty drawing lines between. I am unable to concretely isolate teaching biology from learning biology despite the fact that I have acquired preferred approaches to being taught biology, to teaching biology to others and to doing biology. I have come to understand that each aspect of my education and training is melded in to my current conception of being a biology student, a biology teacher and a field botanist.

Research intent

Self- reflection was the initial stimulus for this research project. Identifying a personal perspective on biology teaching and learning served as the precursor for my desire to examine the conception that academic biologists have of the biology that they teach to students in universities and of the biology that students, including themselves, learn. Said another way, I wanted to know how academic biologists define biology, how they describe doing biology, what their thoughts are about the way biology was taught to them and what they think about their own instructional practice. Similarly, I was curious about what academic biologists think about learning biology, particularly how they learned/learn biology themselves but also how they perceive biology is learned by students in their classes.

My research acknowledges the suggestion that scientists (including biologists) in a university environment have developed perspectives on their discipline through experiencing it. Scientists construct, maintain and pass on their perspectives to subsequent generations of scientists. Through teaching, mentoring and apprenticeship, scientists provide students with opportunities for developing attitudes, skills and knowledge of science with which to gain perspective, achieve identity and begin to experience being a scientist themselves (Campbell, 2003; Hunter, Laursen & Seymour, 2007). What do scientists, more specifically biologists, think about experiencing biology education?

I am fully aware that not all biologists are actively involved in teaching biology, at least formally. Similarly, not all biologists have an academic degree in the subject area. There are workers in government departments, consulting companies and non-government organizations who are designated as biologists according to hiring frameworks or staffing designations at said institutions despite these individuals having no post-secondary education in biological sciences. Public school biology teachers might have a university degree in biology but have typically never worked as biologists, in academia or elsewhere. There are also self-taught people who are recognized in the work place or in research programs for their biological skill and knowledge. In essence, the title of "biologist" is one that has no clearly distinct association with a prescribed education path or practice. Therefore there is need to clearly define the target population of my inquiries, namely academic biologists.

Clarification of terms

For the purposes of this study, I will be using the following definitions of terms that are pertinent to my research:

- biology is a branch of knowledge that deals with living organisms and vital processes. It has many sub-disciplines or fields of study and/or research depending upon the organism or system of interest (Campbell, 1996).

- biologists are individuals who involve themselves (professionally or otherwise) with the science of biology (Janovy, 1985).
- academic biologists work at a post- secondary education institution. They have acquired advanced academic degrees in a sub-discipline of biology and their day to day activity involves teaching post secondary level biology courses and undertaking biological research. The terms academic biologist, university biologist, biology professor and biology faculty will be used interchangeably in this study. Also for the purposes of this study it will be understood that biology teachers work in high schools and science educators are university professors or instructors who focus on science teacher preparation.
- biology education encompasses both the teaching and learning of biology in secondary and post-secondary institutions.
- secondary biology is biology education at the high school level (grade 11 and grade 12 in New Brunswick but designated in different ways elsewhere in Canada and internationally).
- tertiary biology is biology education at the university level (i.e. post-secondary biology).

Organizing framework

This study focused on biology faculty who teach. It employed a phenomenographic approach to explore academic biologists' conceptions of teaching and learning biology. Essentially this study was about conceptions. Pratt (1992) defines this term as follows:

> Conceptions are specific meanings attached to phenomena which then mediate our response to situations involving those phenomena. We form conceptions of virtually every aspect of our perceived world and in so doing, use those abstract representations to delimit something from, and relate it to, other aspects of our world. In effect, we view the world through the lenses of our conceptions, interpreting and acting in accordance with our understanding of the world (p. 204).

Other researchers (Akerlind, 2011; Taylor et al., 2008; Brown, Abell, Demir & Schmidt, 2006; Kember, 1997; Samuelowicz & Bain, 1992; Trigwell, Prosser & Taylor, 1994) refer to beliefs, perspectives, views, understandings, and awareness interchangeably with the term "conceptions". In that light, all of these words were used in my research study to refer to the range of ways that the study participants have experienced biology education.

Research questions

The broad domain for this research was biology education in terms of the experiences that academic biologists have with teaching and learning that science subject and discipline. Therefore the overarching focus question was:

A) What conceptions of teaching and learning biology are held by academic biologists?

The subsidiary questions guiding my research were:

a) How do academic biologists experience learning biology?

b) How do academic biologists experience teaching biology?

c) Are there any implications of academic biologists' conceptions of teaching and learning biology for secondary school biology curricula?

Rationale

A familiar quip in discussions about how anyone sees educating and being educated is "we teach the way we were taught" (Oleson & Hora, 2012). In my opinion, reflection on one's conception of teaching and learning can inform one's practice. Therefore, at the beginning of this study I felt confident that a research idea that would encourage academic biologists to reflect on their conception of teaching and learning biology had potential to inform that aspect of who they are as a biology teacher and a biology learner.

Furthermore, based on my work in secondary biology curriculum development, I felt that by discovering the conceptions that academic biologists have about their own high school experiences with biology teaching and learning, there would be implications worthy of consideration regarding essential elements of future secondary biology curriculum revisions. In my experience, academic biologists are usually not active participants in school curriculum development committees, merely advisers in the process (Morrow, 2003; Drayton & Falk, 2006; Kim & Fortner, 2007). I considered this to be a disconnect worthy of further study and Crosby (1997) provides rationale for my opinion. He notes that while it is important to have curriculum design experts, teaching methods experts and content experts involved in school science curriculum development, there is also a need to "include those who practice science" (p.271). He considers that a school biology curriculum must be an experiential one in which the biology teacher is expected to have students doing biology to learn biology. He feels that when it comes to developing science curriculum, specialists in education and scientists should not work in isolation from each other. Clarification of the conceptions held by academic biologists in this matter is needed.

Significance of the study

The significance of this study is that there is a gap in understanding of the entire spectrum of biology education because little or no research has been done about the conceptions that academic biologists have of biology teaching and learning.

While not targeting biology teaching or learning specifically, education researchers have worked in the area of scientists' conception of science education in schools. In one such study, Taylor et al., (2008) found that scientists had formed very "distinct and critical views of science education" (p. 1069), despite the fact that they had very limited experience with science teaching and learning in schools other than what they could relate to from their children's education or from their recollections of their own school days.

While not targeting scientists specifically, studies by Prosser, Trigwell and Taylor, (1994), Orsmond, (2007), Brownell & Tanner, (2012) and Mulnix, (2012) examine conceptions of science education held by academics in education faculties rather than science faculties.

Scientists' conception of their experiences in public education, community service, professional development of teachers and mentoring of young people interested in science have been the research focus of still another category of studies, but none of them were specifically about academic biologists (Banner et al., 2008; Barab & Hay, 2001; Bianchini, Whitney, Breton, Hilton-Brown, 2001; Finson, Thomas & Pederson, 2006; Melear, 1988; Robertson, 2007; Southerland, Gess-Newsome & Johnston, 2003; Thiry, Laursen & Hunter, 2008).

So while all of these studies relate to scientists as a collective entity none of them have associated their results directly with a scientist's unique areas of expertise. In other words, the findings are generalized rather than being specific to a chemist, a physicist or a biologist. Instead, they posit that a scientist is a scientist. This means that they can largely be used to inform broad issues, particularly curriculum development and implementation, in science education rather than those of individual disciplines. The significance of this study is that its findings pertain to biologists and the teaching and learning of their field of science explicitly.

Situating myself in this research

My favorite high school subject was biology. I readily credit my high school biology teacher with influencing my decision to obtain a Bachelor of Science degree and my desire to become a biologist. I also give him credit for guiding my decision to acquire a Bachelor of Education degree, with a specialty in science, so that I would have professional qualifications to teach the subject I love to young people. Throughout my career I've interwoven teaching biology and doing biology in various ways. Despite having progressed to a professional level in the fields of education and science, I consider myself to be a life-long learner and, as such, an on-going biology student.

I realize that these experiences create a lens through which I visualized and implemented my plan for this research project. I also realize that it was important to acknowledge the potential influences of these experiences on my research data analysis. For that reason I am following the recommendation of Webb (1997) to make my background as a researcher clear and transparent so that the readers and users of my findings are informed about factors that had the potential to affect the study results despite my intention to strive for there to be as little bias as possible in my work. That said, allow me to further elaborate on the aspects of myself that I bring to this study.

I hold a New Brunswick teachers license and have taught middle school science and high school science, biology and chemistry in the province. My science teacher credentials qualified me to spend four years as a member of the New Brunswick Department of Education's Curriculum Development Advisory Committee for Secondary Science. They also qualified me to accept the position of faculty associate at the University of New Brunswick's Faculty of Education where I spent three academic years as an instructor of science teaching methods courses for pre-service teachers.

I have a Master's degree in biology. During that program of study and research I gained experience in designing and conducting scientific experiments, in writing a thesis and in defending my findings. Through these endeavors, I learned firsthand about biology and doing biology.

I have had a long career in the field of biology. I have held various positions including ones in research and in consulting as a field botanist and wetland biologist.

These jobs have allowed me to learn about the biology profession while working with and/or reporting to academic biologists, government biologists, industry biologists and/or other consulting biologists. My expertise as a botanist has qualified me to be a member, with other scientists, of the New Brunswick Department of Natural Resources Vascular Plant Status Group and the City of Fredericton's Tree Commission.

I was a sessional lecturer in the University of New Brunswick's Department of Biology for a decade, with responsibility for teaching undergraduate courses in plant propagation, economic botany and plant taxonomy.

Finally, in an earlier phase of my PhD program I was involved with a longitudinal qualitative research program about informal science education for middle school students. And in another phase of this degree, I conducted two different pilot studies. One involved investigating the understanding that my research participants had of the term "scientist". The other study involved me asking a group of scientists, including individuals from industry, government, the consulting community and university to describe their perspectives of scientists' roles in education.

Structure of this dissertation

Before concluding this introductory chapter, I will explain the structure of the remaining sections of this dissertation. In chapter 2, I review literature about biology education from three experiential perspectives which I have deemed relevant to my study, namely: experiences of teaching biology and of learning biology as a subject area and a discipline; experiences of biology education reform; experiences of biology education beyond the Academy.

In chapter 3, I review literature about phenomenography which is the methodology that directed my investigation. My goal in the early sections of this chapter is not to simply contrast phenomenography with other qualitative research methodologies but to sufficiently familiarize readers with the history, the theoretical underpinnings and stages of the phenomenographic process that they are able to understand how I conducted my research. My goal in the last sections of this chapter is to present a detailed account of my research process.

Chapter 4 is dedicated to presenting my research results: descriptions of the collections of themes of awareness from which I defined and named my study's categories of description; two different formats of the study's outcome space. The primary focus of this section will be the revelation of the dimensions of the categories that represent academic biologists' conceptions of biology education. The secondary focus of this section will be the rationale for the hierarchical structure of the outcome space.

Finally, chapter 5 presents a discussion of my findings from the perspective of the answers they provide for the guiding questions of my study. The discussion will also focus on the way I link my work with components of my literature review and it will address the implications my study has for the secondary biology curriculum. I will end the chapter by outlining the additional questions that my findings have generated.

Chapter 2 Literature Review

> As a biological scientist, you have a hierarchy of responsibilities, not the least of which is to bring your understanding to a world that, without it, will make choices that negate the values for which you stand: the values that derive from a naturalist tradition, a reverence for organisms, and a commitment to a lifetime of learning and teaching (Janovy, 1985, p. 154).

This study focused on academic biologists' conception of their experiences with teaching and learning biology. My search of education research literature uncovered no reports from studies with this specific concentration.

However, there is a significant body of literature about post-secondary science education that portrays biology as a subject area and a discipline. Since it is typically the case that academic biologists have successfully navigated their way through several biology degree programs, it is reasonable to believe that the experiences they had while doing so would have resulted in a residue of influence on their daily practice and on their conception of the education stream that prepared them for a career in academia. For this reason, I believe that this body of literature can inform my study.

There is also education research literature about reform in biology education both at the secondary and post-secondary levels. I will explore this literature since there is potential for academic biologists' conceptions of biology education to be influenced by their experiences with curriculum implementation and development.

Finally, there is a body of education research literature about the involvement of scientists in K-12 schools. I will briefly examine aspects of this literature that pertain to academic biologists' role outside of the Academy. This will allow me to expand on the idea that academic scientists have experiences with education, in the form of outreach beyond academia that can influence their conceptions of the biology curriculum that precedes university.

I begin by presenting a snapshot of the impressions that researchers have written about academic biologists' experiences as teachers. I ask the reader to remember that this is a documentation of that teaching as interpreted by an education researcher rather than from the perspective of an academic biologist. In other words, it is from a first order perspective rather than a second order perspective.

About the experience of teaching biology

When it comes to the generalized topic of instruction, there is an assumption in the field of education that everyone understands what is meant when one talks about teaching because most people have been taught. However, Pratt (1992) finds flaws in that assumption because, to him, "to teach means different things depending upon one's values, beliefs, and intentions" (p. 203). In other words, not everyone understands, in the same way, what is meant by teaching.

Assumption- related flaws certainly exist when it comes to the specific topic of biology education. It is well established in the literature that not everyone understands, in the same way, what it means to teach biology (Ebert-May et al., 2011; Friedrichsen et al., 2009; Gibbs & Coffey, 2004; Musante, 2005). Indeed, particularly at the post-secondary level, teaching biology has a variety of interpretations (Kusch, 2009; Pareja, 2009).

It is possible to argue that to teach means acting on one's own experiences as a teacher and as a learner (Kember, 1997; Samuelowicz & Bain, 1992; Tamir & Jungwirth, 1972). As well, one can posit that "course structures and instructional actions are often influenced and mediated by a teacher's past teaching and learning experiences" (Southerland et al., 2003, p. 669). By extension, to teach biology might mean implementing one's conception of one's own experiences as a biology teacher and a biology learner. But what evidence is there to support this being the case?

In his description of how science faculty members view and engage in the process of preparing the next generation of scientists, Campbell (2003) recognizes teaching as a major component of doing science in the university environment. At the same time he acknowledges that the ways in which scientists understand teaching vary depending on the scientists' personal views of their discipline. He suggests that, based on a scientist's perspective of what is or isn't important for students to learn about a specific area of science, the actual content of science courses and instruction will vary. Through formalized courses, scientists in universities present their worldviews to prospective members of the academic community and provide those students with opportunities to develop attitudes, skills and knowledge that are appropriate to the discipline at hand (Campbell, 2003).

That said, Kafatos and Eisner (2004) suggest that "the life sciences are undergoing a profound transformation" (p. 1257) such that they are no longer the narrowly defined domains of botany, zoology and microbiology. This compounds the matter of establishing what should and shouldn't be present in biology curricula best suited to prepare students for careers in any specific area of biology.

Even though the process by which it is arrived at is not clear, there is evidence to support the general agreement among academic scientists about the signature of a successful undergraduate science degree. That signature is the acquisition of the abilities required to interpret data, solve problems, design experiments, do scientific writing, communicate orally, critically analyze primary literature and work collaboratively (Andrews, 1964; Bergstrom, 2011). Scientists practice these skills daily so why are they not being specifically taught to undergraduates in an explicit and scaffolded manner? Frequently, undergraduate biology courses are intent on the delivery of vast amounts of facts. There is seldom a prescribed course through which biology students master process skills (Coil et al., 2010).

The distinct opinions that scientists have about what should and should not be included in the courses they offer are often tempered by still other influences. These include a professor's ability to cope with constraints such as time (duration of individual teaching sessions, number of teaching sessions in an academic term), the suitability of classroom space (seating arrangements, lighting, sound systems) and access to support services such as student learning centers, library and technology staff expertise and/or the involvement of graduate student teaching assistants (Oleson & Hora, 2012). As well, course offerings are influenced by an academic's personal plans to address the nature of student diversity (related to the school systems that students came through and/or their cultural backgrounds), ever-more complicated technological advancements (smart classrooms, media labs) and the need for greater emphasis on the thoroughness of a course syllabus (inclusion of learning objectives and measure of success). In the estimation of Pareja (2009), today's science faculty members require a range of abilities, skills, knowledge and understanding unlike in previous times; times when being a good researcher was the most important job requirement for academics.

A compounding factor in the teaching experiences of academic biologists relates to the administrative authority that governs the teaching environment. In some cases faculty members have total autonomy for their teaching assignments meaning that they are the ones who decide on the course content, the mode of teaching and the processes for student assessment (Campbell, 2003). In other cases, faculty members are expected to tailor their instructional strategies to match the faculty standard. This often includes a need to subscribe to the idea that the teaching work of faculty is always subordinate to the research work of faculty (Shulman, 2011). After all, research skills frequently trump teaching skills as major criteria for hiring academics (Fleet et al, 2006). Indeed, this conception of the importance of research over teaching begins early in the graduate training phase of a university biologist's education.

Kusch (2009) describes the transition from being a graduate student to becoming an academic biologist as progressing from the status of a beginner to the status of being a specialist in one's field. Given that teaching is a major responsibility for academics, it would therefore follow that as graduate students in biology undertake their degree programs they move from being novice teachers to being teachers with advanced competence (Campbell, 2003; Hunter et al., 2007). However, according to Gaff and Pruitt-Logan (1998):

> Many graduate students acquire no experience in the complex tasks of teaching: determining proper goals for student learning; designing courses, selecting learning materials, making assignments, and assessing the achievement of those goals; understanding and working effectively with diverse students; giving academic and career advice; and constructing and assessing curricula in the

> department. Too many of those who do serve as teaching assistants are given only minor assignments and receive little or no orientation and mentoring to master these tasks (p. 77).

Offering a slightly different perspective, Brownell and Tanner (2012) claim that most graduate students in biology experience an “apprenticeship of observation” (p. 342) with respect to learning how to teach, meaning that they model the teaching approach of their supervising professor. It is typically the case that scientific language, research approaches and training styles are the valued credentials that are passed from mentor to student, whereas a focus on teaching expertise is often trivialized (Sung et al., 2003).

Perhaps a graduate student’s opportunity and desire to gain teaching expertise is a more individually driven endeavor, however. Janovy (1985) personalized the decision to become an academic biologist. He feels that by deciding to become an academic biologist he was required to adopt a life, beginning when he was a graduate student, which was dedicated equally to teaching and learning. The teaching that he refers to involved more than a biology professor simply transmitting a series of facts to his students. He elaborates on this viewpoint as follows:

> In an average large university, a biologist walks into an auditorium in late August and stands in front of three hundred freshmen. If the responsibility is to be fulfilled, then four months later the three hundred must walk away aware of themselves as individuals, as part of a large and complex, yet closed, environment, and as a small yet significant part of a four-billion-year progression of life forms (p. 143).

> Obviously, among the list of intellectual weapons should be the professions' world view. If it is not expressed, then the biologist will not bring to society his or her essential contribution: one version of the truth. We will then produce another group with biology on the transcript but not much that passes for biology on the mind. Such a group will have little potential for making rational decisions on major issues involving the life of the species. If a student leaves biology class with information, but without the vision to see beyond the surface and into the structure, process, complexity and dependency, then we have not actually taught biology (p. 13).

With similar intent, Atkinson (2001) proposes that university teaching be a process of transmitting perspectives, skills and knowledge to others, with the professor being the vehicle that drives student understanding. In her point of view, tertiary teaching should not be "an erudite, narcissistic lecture that entertains the speaker and fills class time, but bores students" (p. 1221). A university teacher not only needs to know the content of her discipline but also the most effective methods through which to teach it (Atkinson, 2001; Orsmond, 2007).

Based on the results of a study involving new science faculty, Boice (1991), reports that new faculty can be aided in their learning to teach process by actual classroom experiences, by interactions with their new colleagues, and less from senior faculty (Boise, 1991). But few additional studies have had a similar focus meaning that there is a limited understanding about curriculum enactment by scientists (Southerland, Gess-Newsome & Johnston, 2003) and about how faculty establish their teaching styles (Boice, 1991).

Akerlind (2008b) offers the opinion that the universities attempting to implement change in teaching strategies amongst their faculty are aware of the importance of identifying academics' conception of teaching, particularly their discernment of what distinguishes teacher-centered and student-centered instruction. She characterizes teacher-centered instruction as being when the academic takes for granted that students are learning what they are being taught. Teacher-centered instruction aims to provide students with a foundation of content knowledge because "students will learn effectively only what we tell them in class" (Knight & Wood, 2005, p. 306).

Akerlind (2008b) characterizes student-centered instruction as being when an academic focuses specifically on what the students are experiencing and what impact that experience will have on the students' learning. Student-centered teaching aims to infuse biology students with an appreciation of the study of biology (Coil, Wenderoth, Cunningham & Dirks, 2010).

An overall impression of the literature about scientists' experiences with teaching tertiary science is that it describes a wide variety of influences on which conceptions can be formed. Those conceptions are likely to be compounded by ways in which academic biologists experience biology learning, thus the next section of this chapter will address that area of a biology professor's life and work.

About the experience of learning biology

All academic biologists have been students/learners themselves at one point in time. The fact that they have been successful at acquiring the credentials of a biology professorship suggests that their experiences as students were productive. What would those experiences have included?

Andrews (1964) places the following slant on the education that biology students should have during their training in the discipline:

> It is essential, I think, that a biologist, in his undergraduate education, obtain breadth and some depth in the life sciences. He must study in the laboratory and in the field in areas of botany, zoology, and microbiology. He must study at all levels of biological organization: molecular, cellular, organ and organ system, organism, community, and biogeographical. He must be exposed to descriptive as well as experimental biology. He must participate in laboratory and field work in which the learning of scientific names or parts is essential. He must have an active role in course work in which dealing with abstractions and the history of biological thought is of essence. He must be involved in independent study in which the investigatory nature of the life sciences becomes self-evident. He must, during his undergraduate education, be engaged in a composite of experiences which are aimed to help him develop knowledge, skills, attitudes, and desirable behavior patterns (p. 17).

However, along with placing value on these specific course and practical work requirements, there is an ongoing debate about how learning occurs, particularly about how biologists develop intellectually and personally through their degree programs (Hunter, Laursen & Seymour, 2006). Generally speaking students have limited awareness of their own learning and are often unable to decide whether, for them personally, learning is memorizing or learning is a meaning-making process that helps them be able to understand (Boud, 1993). The former is likely to be the explanation prescribed to by students who adopt a shallow approach to learning a topic while the latter is likely to be an explanation prescribed to by students who learn and think deeply (Trigwell & Prosser, 1997).

This generalized perspective about learning is applicable to the specifics of biology education. There are always undergraduate biology students who thrive through post-secondary biology education whether or not there has been any effort made by the instructor to accommodate their learning style preferences. These students learn and think deeply (Trigwell & Prosser, 1997). However, there are other undergraduate biology students who either struggle through their entire degree or who fail early on in their program (Flannery, 1998). These students have less developed conceptions of what it is to learn biology (Trigwell et al., 1994) which usually means that they find learning biology very difficult (Cimer, 2012).

With respect to their teaching responsibility academic biologists can identify two important purposes for introductory biology courses. Firstly, it is critical for the initial learning experiences of university biology students to be ones that attract, motivate, and begin preparing the next generation of biologists. Secondly, first year biology courses need to be where non-biology majors are exposed to teaching through which they acquire the basics of biological literacy (Woodin, Feser & Herrera, 2012).

Despite the intended purpose of introductory biology courses, research shows that the relevant success/failure ratio amongst university biology students can be attributed to whether or not they cope well with learning biology in lecture-based course. Wood (2009) elaborates on this point of view in the following way:

> Traditional teaching methods do not prevent the progress of superior students from introductory courses to upper-level courses to graduate training, where they may become experts in their fields and develop into skilled researchers. But the traditional methods fail the majority of students who leave our introductory courses viewing biology as a large collection of disconnected facts that have little relevance to their daily lives and will soon be forgotten (p. 516).

When the average student is faced with lecture-based introductory biology courses, they tend to conceive of their biology learning experience as having little relevance and as being unworthy of pursuing further than necessary (Tanner & Allen, 2004; Wood, 2009). These beginner biology students reject the need to cover the jargon and the details of biological concepts. To them, the face-to-face time in first year biology lectures represents no more than repetition of the material they were required to cover themselves in assigned text readings and/or web content review (Wood, 2009).

Cimer (2012), while reporting the findings of a study that was informed by the work of several other researchers (Johnstone & Mahmoud, 1980; Finley et al., 1982; Tolman, 1982; Anderson et al., 1990; Seymour & Longdon, 1991; Lazarowitz & Penso, 1992; Chiapetta& Fillman, 1998; Bahar et al., 1999), suggests a number of reasons why many biology students find it hard to learn biology whether or not lecturing is the teaching strategy:

- biological concepts are often presented in abstract and, therefore, confusing ways
- there is limited application of course materials to real-world scenarios
- the language of biology is foreign and complex

- biology curricula are overloaded and time constricted (thereby promoting memorization over meaningful learning)
- learning environments are designed with limited consideration of students' interests, learning style preferences and expectations
- creative expression through discussion and open-ended explorations is lacking

This criticism paints a harsh picture of the introductory biology courses that are pre-requisites for students majoring in biology. But it would seem to substantiate the impression held by many that such pre-requisite introductory biology courses are designed to identify students who are not apt to progress to more advanced biology courses. Bergstrom (2011) describes them as "weed out" courses (p. 35) that are purposely exclusionary because they promote a learning environment that is devoid of pedagogies that engage students and promote meaningful learning of biology. By focusing on knowledge transmission and on soon-to-be-outdated facts about biology (Morse, 2003), they represent a teaching strategy that is not effective for all students (Novak, 2011).

As an ending point for this review of literature about learning biology, it can be said that becoming an academic biologist begins by one becoming a biology student who learns about biology and about how to do biology (Hodson, 1986). Becoming a biologist also involves learning the attitudes, skills and knowledge appropriate to the discipline (Campbell, 2003). In anticipation that becoming a biologist might require one to consider changes to traditional learning environments, I will move to the next topic in this literature review which will focus on what education researchers think about biology education reform, with emphasis on the situation at the post-secondary level.

About experiences of biology education reform

Momentum has been growing for some time for a revolution in the way biology is taught, beginning in high schools (Windschitl, Dvornich, Ryken, Tudor & Koehler, 2007; Wood, 2009) and continuing onwards to universities (AAAS, 2009). Richmond et al., (2010) describe this as a much needed "recalibration" (p 441).

Research about the traditional teaching methods employed in undergraduate introductory science courses (e.g. lectures, small group teaching, laboratory teaching, project supervision) typically focuses on whether or not such instructional approaches are optimal for promoting student learning (Kember, 1997; Kusch, 2009). Findings have shown that alternative, research-based teaching methods (massive open on-line courses/MOOC; self-directed, inquiry based learning modules; group problem-solving assignments) have been shown to be more effective (NRC, 1996; Handelsman et al., 2004; Mackness, Mak & Williams, 2010). A small but growing number of informed faculty and administrators are pushing for their adoption (DeHaan, 2005; Singer et al., 2013). The buy-in is not commonplace, however. Indeed, the impression remains with a large majority of academic biologists that biology content is most efficiently transmitted to students through lecture-based instruction (Mulnix, 2012).

According to Brown, Abell, Demir and Schmidt, (2006), poor teaching is a major complaint of students majoring in science at universities. Poor teaching in this regard means a lack of student-teacher dialogue, a focus on memorization of facts without any obvious illustration of the applicability of those facts, no opportunity to ask questions and no encouragement to engage in problem solving.

Perhaps the complaints of first year biology students can be attributed to the fact that science curricula in secondary education have increasingly placed emphasis on the implementation of diverse instructional strategies that are student-centered and inquiry based (Ajewole, 1991; Bencze & Hodson, 1999; Taraban et al., 2007; NBDED, 2008). Beginning undergraduate science students might have the impression that the learning environment in their university course will be similar (Brown et al., 2006). It is a curious phenomenon given that science faculty have been students for many, many years themselves and therefore should be able to relate to what students think of as good teaching (McKeown, 2003).

Lecture-based teaching is not a significant issue for Janovy (1985) who notes that "most of the biology has been done for beginning students by the time they enter a lab to do a formal exercise…in the interest of economy" (p. 39). He continues with the idea that "important questions and problems are really ones that the present generation of scientists has been working on for some time". This justifies the reality of professors telling students what it is they need to know.

In their defense, the academic biologists who are intractable about traditional ways of teaching can readily identify colleagues who have flourished in an education system that has predominantly been based on lectures or on activities/investigations that use a pre-established, step-by-step approach, with pre-determined outcomes, so as to equip students with a solid foundation of knowledge (Bower, 2005; Coil et al., 2010; Handelsman et al., 2004). Additional rationalization for lectures lies in the mindset that, by continuing to teach in a traditional fashion, academic biologists are modeling the pedagogical approaches of their own professors and mentors. To do otherwise would be disrespectful (Bronwell & Tanner, 2012).

In essence, academic biologists have themselves been successful in a traditional educational environment that was governed by their predecessors. Why would they not want to adopt that very same approach for their own student (Wood, 2009)? As well, apprenticeships, mentorships, internships and similar approaches to preparing subsequent cohorts, typically expect the novice to adopt the ways of the guiding expert (Hunter et al., 2007).

Flannery (1998) identifies her own areas of concern about subject matter appreciation being trumped by the importance of how it is taught. In her words,

> It is not easy to strike a balance between love of subject matter and love of teaching. At the beginning of our careers, I think the subject matter usually wins. We are fresh from our own education and chuck full of information that we can't wait to impart to others. The problem is that we have little experience in the imparting process. Even with education courses as a guide, there is a great deal of trial and error before we become even decent teachers. But as this evolution takes place, there is danger that the pendulum will swing too far in the other direction and that the teaching will dominate the subject matter. By this I mean that a teacher can become more interested in how to present material than in the material presented. This has always bothered me about education programs and is one reason that I resisted getting a degree in education for many years. I love biology

> and when the medium – the teaching technique- begins to overwhelm the message – the biology – I start to get queasy (p. 223)

Similarly, by offering up the following scenario Sunal et al., (2001) captures the stress experienced by a biology professor who, in the process of developing a new course, realizes that content and content delivery involve difficult decisions and complicated skills for academic scientists:

> Date: Friday, 27 September
> From: cathann@sciteach.edu
> To: chris@univ.edu
> Subject: "Catch 22"
> Hi, Chris:
> Thanks for sending the physical science course syllabus via e-mail. It looks like you have a very interesting course. Creating my new course for next semester is proving to be difficult for me. Let me explain.... First, I feel the primary responsibility that I have is teaching my students to understand science. The administration, however, does not seem to see it that way! In fact, they think each course only takes the actual class time plus a little time out of class to do all the planning and assessment necessary. I find I am putting in eight-hour days to just stay ahead on the classes I am teaching right now. This does not leave much time for creating the new physical science course! Second, spending the extra time on planning the new course is cutting into my research time. You know the old "Catch 22." You have to do research to publish, publish to get tenure, and at the same time teach, advise, develop new courses and serve on committees. Why do the priorities seem to be so displaced in higher education? Is there anything to be done about it? Third, I am having trouble getting my colleagues in the sciences to see a need to put effort into a different way of teaching science. Our lecture courses have high

> attrition among all students, even some of our brightest students, most of whom would be excellent in a science career. I have informally asked many of my former advisees why they were changing their majors, and a majority has said the classes were exercises in memorization techniques. They were intimidated by the content. Besides that, most felt like they got little out of the courses and were changing their majors "to more relevant" ones. Chris, I am beginning to question my choice about leaving government research for academia. I never knew there were so many factors that go into creating an innovative course. Please give me some insight about how you would create change in this course without alienating yourself! I need some guidance from someone who has been there. Frustrated! Catherine Ann

This memo illustrates an acknowledgment that traditional pedagogical approaches in undergraduate introductory science courses (i.e. large classes and hour-long lectures) do not work effectively for most students. But that acknowledgement is accompanied by a limited understanding of how to alter their teaching approach to help students learn (Sunal et al., 2001).

The fact is that, until recently, academic biologists have had limited involvement in biology education research. More often than not, such research has been conducted by academics who have a scholarly background in science but who are associated with faculties of education (Rutledge, 2013). These science education researchers write predominantly for the education community. That means that the results of work they do about teaching and learning biology at the post-secondary level are not often consulted by university scientists. Indeed, biology faculty members are usually oblivious to it. And even if academic biologists make the effort to identify relevant biology education literature, they may find that the language used is alien, that the research concepts being written about are unfamiliar and that the research methodology is one that they have no experience with (Orsmond, 2007).

This disparate researcher background also introduces a trust and confidence issue for academic biologists. While many scientists are trained to value and uphold the research process, that regard is not necessarily universal, particularly when it involves respecting qualitative, rather than quantitative data about the positive attributes of student-centered teaching (Anderson et al., 2011; Handelsman et al., 2004). Essentially, scientists share the perspective that "educational research lacks validity and rigor" (Anderson, 2007, p. 465).

According to Michael (2007) academics in science faculties rarely have formal training in pedagogy. If they spend time and effort trying something new, they often do so without realizing that there are already effective, well documented approaches available for them to embrace. "Although some professors are using innovative teaching methods in their university biology classrooms, they may lack the knowledge, skills and support to research other promising learning methods" (Stagg, 2008, p. 389).

Added to that is the issue that faculty are often of the opinion that it is their job to teach students biology, not to have to teach students how to learn (Tanner, 2012). Mulnix (2012) classifies this as an intractable, entrenched behavior.

Academics' development as teachers and their subsequent teaching success have traditionally been categorized independently from other aspects of their work performance (Akerlind, 2011). Only recently has more emphasis been placed on the fact that professors' primary responsibilities are two-fold namely the generation of new knowledge through research and the education of students (Anderson et al., 2011). There is no indication, however, that this emphasis predicates the establishment of a science faculty culture where teaching responsibilities are balanced with research endeavours. As a matter of fact there is little information available about the way scientists interpret and respond to efforts to reform post-secondary science education (Southerland et al., 2003).

Nonetheless, with respect to biology education reform in universities Wood (2009) recommends that academic biologists give consideration to the adoption of these best practices:

- prior knowledge of students should be the starting point for biology instruction
- teaching strategies should be varied so as to meet the needs of the diverse learning needs of students in an optimal way
- formative assessment should be routine and used to provide feedback to both the biology professor and his or her students
- peer interaction, collaboration and group work should be valued as a way for individual students to investigate their own understanding of science concepts
- active learning (group discussion, applying concepts, problem solving, independent study) should augment or replace passive learning (listening to lectures, note taking, textbook reading)

Essentially, the accommodation of these best practices aligns with Shulman's (1987) belief in the existence of a "knowledge base for teaching" (p. 4), which has come to be known as pedagogical content knowledge (PCK). Within a PCK perspective, capacity for improvement in teaching by academic biologists would blend a knowledge of what is to be learned (i.e. what content to teach) with how it is to be taught (i.e. pedagogical strategies through which "the unknowing can come to know, those without understanding can comprehend and discern, and the unskilled can become adept") (Shulman, 1987, p. 4).

The National Science Foundation (NSF, 2009) has also made recommendations for academic biologists to consider with respect to biology education reform. These include setting up a reward system that would recognize faculty who adopt student-centered teaching strategies, and making a commitment to elevate the scholarship of teaching and learning to a professional activity (p. 11).

In this light, it seems that one of the most important factors in the success of undergraduate education of biologists is the quality of the faculty with whom students are associated both in the classroom and in the laboratory. For that reason, being an academic biologist infers having an expertise in instruction and research (Andrews, 1964). D'Avanzo, Anderson, Hartley and Palaez (2012) strongly believe that biology education reform is required for this to become reality. The fundamentals of that reform include "a major shift in faculty members' beliefs about teaching biology, effective rewards for faculty members who make the effort and effective learning communities for faculty members striving to reform their teaching" (p. 416).

Academic biologists who become renowned for the quality of their teaching and research, they are often asked to become involved, in a variety of ways, with the broader community of biology education. This aspect of a biology professors experiences is the subject of the next section.

About experiences of biology education beyond the academy

Academic biologists have a wide variety of opportunities through which they can experience biology education in environments beyond the university. Often K-12 teachers invite academics to visit their classrooms to speak to students about doing biology and about being a biologist (Drayton & Falk, 2006; Kim & Fortner, 2007). Professors who accept these invitations become role models to students. They can cause a change in students' stereotypical image of scientists and help students realize that scientists are real people (Painter, Tretter, Jones & Kubasco, 2006). At the same time they can engage in the intricacies of the school world, the school science curriculum therein and the pedagogical practices used in classrooms (Sweeney & Paradis, 2004).

Scientists have also been involved with bringing the results of current science research into the curriculum (Drayton & Falk, 2006; Kim & Fortner, 2007). Associated with that endeavor, they have been asked to participate in the development of educator guides for curriculum delivery by teachers (Morrow, 2003). In the long term, Swinehart (1991) thinks that scientists' involvement in science curriculum development facilitates society's ability to make informed decisions about the complexities of today's world.

That said, in some instances, various tensions arise from scientists' involvement with the setting up of science curriculum and science learning objectives. Sometimes this tension is due to the ignorance of scientists about the curriculum development process. Bower (2005) suggests that curriculum development is a much more costly and time consuming process than most scientists believe. Added to that, he points out, is the concern that many universities provide no incentive or reward for scientists taking that time away from their academic work to involve themselves in curriculum development for other levels of the education system. Kim and Fortner (2007) note that the professional culture in a university acts to impede collaborations between scientists and schools or between scientists and curriculum development committees of government departments of education because such collaborations are not measurable as part of the professional work of a scientists (i.e. teaching/research/university service). According to Ecklund, James and Lincoln (2012):

> Scientists also perceive that they are rewarded little for science outreach work, especially in the tenure process. Outreach may be seen as outside of the responsibilities of the university scientist, an understanding tied in large part to institutional norms at top research universities that value research productivity over other types of contributions. Adherence to these norms limits the time and ability of scientists to take on other projects and even creates disincentives for participation in outreach–often in the form of disapproval by mentors or department heads (p. 5).

Specific tensions can arise because of other misconceptions that scientists hold about the school science curriculum. For example, as noted by Morrow (2003), scientists often fail to recognize that what worked so well for them in school may not work as well for the majority of students who will not become scientists. Jenkins (2008) corroborates this by noting that scientists are experts in a narrow area of science and do not understand what is necessary for a science education that is broadly based and directed at all students, not just those who plan for a science career. From this perspective, therefore, scientists should only serve in an advisory capacity, when it comes to curriculum development (Jenkins, 2008).

Ritter (2008) has also developed the opinion that scientists are not the right people to have involved in matters related to school science curriculum development. He bases this opinion on his experience with scientists who complain about the students that they see in their classes not being properly prepared for university level science. The basis of these complaints is the curriculum that was followed in their previous education environment.

Before ending this chapter and moving to a review of the methodology that I chose to guide my research, I ask the reader to recall that I was unable to locate any second order perspective studies that specifically target conceptions held by academic biologists of their understanding of teaching and learning biology or biology curriculum development and implementation. However, I am able to summarize the science education research literature that I consulted about the related topics of university level science education, reform in biology education and the involvement of scientists in schools, in the following way:

- Teaching science at university usually means implementing one's conception of one's own experiences as a teacher and a learner ((Kember, 1997; Samuelowics & Bain, 1992; Southerland et al., 2003; Tamir & Jungwirth, 1972).
- Decisions about the actual content and instruction of university science courses are multifaceted (Campbell, 2003; Coil et al., 2010).
- There is a limited understanding about curriculum enactment by scientist and about how science faculty establish their teaching styles (Boice, 1991; Southerland, Gess-Newsome & Johnston, 2003).

- Introductory biology courses are critical for providing the initial learning experiences of biology majors but also for exposing non-biology majors to the basics of biological literacy (Woodin, Feser & Herrera, 2012).
- Scientists consider that content and content delivery in university courses involves difficult decisions and complicated skills (Sunal et al., 2001).
- The two primary responsibilities of professors (teaching and research) are categorized independently such that research trumps teaching (Akerlind, 2011).
- Tertiary biology education reform requires a shift in faculty members' beliefs about teaching.
- Academic biologists can be involved in biology education beyond the university (Drayton & Falk, 2006; Kim & Fortner, 2007) but there are related barriers (Ecklund, James & Lincoln, 2012).
- Scientists have misconceptions about the secondary science curriculum (Morrow, 2003; Jenkins, 2008; Ritter, 2008).

Chapter 3 Methodology

> Perhaps you remember the story in which a group of blind people encounters an elephant for the first time? One approaches the beast from behind, nervously handling the tail. He shouts a warning " the elephant feels like a snake hanging in the air." For the second, encountering a back leg, the experience is very different: she reports that she has her arms around a warm tree. And so it goes, with others trying to make sense of the hide, belly, trunk, tusks and other bits of the pachyderm's anatomy. The reports are hugely diverse - and yet all are right, to an extent. All the bits add up to an extraordinary, as-yet-invisible whole. (Dosdat & Kalaydjian, 2005, p4)

There are many different qualitative research traditions, each of which has an overall best fit with a research goal or focus and each of which uses a different strategy or approach to link research methods to outcomes (Cresswell, 2003; Reed, 2006; Yates, Partridge & Bruce, 2012). Qualitative researchers understand that no methodology is weaker or stronger than another but that there is generally one that better suits a specific research paradigm (Patton, 1990; Sandelowski, 2000).

Phenomenography is a qualitative research methodology that fits a research situation which focuses on the different ways an individual experiences or understands a phenomenon (Akerlind, 2008a; Berglund, 2004; Booth, 1997; Marton, 1981; Marton 1986; Svensson, 1997). In this chapter I will explain the tenets of this research tradition beginning with an introduction to its founder and an elaboration of his initial rationale and goals. Thereafter I will review the theoretical framework of phenomenography making mention of relevant assumptions and doctrine. I will also outline the methods that are typically used in the application of phenomenography and I will discuss aspects of trustworthiness and quality of a phenomenographical study. With this elaboration of phenomenography as a backdrop, I will then describe my own research process and explain my reasons for believing that phenomenography is the most appropriate research methodology for the purposes of my study.

The origins of phenomenography

The recognized founder of phenomenography is Ference Marton, an educational psychologist at the University of Gothenburg, Sweden. More than forty years ago Marton and several colleagues became interested in the approaches students adopt to learning (Akerlind, 2005; Marton, 1981; Marton, 1986; Marton, 2000; Trigwell et al., 1994). This was in an era of qualitative research when the boundaries of research disciplines were blurred (Denzin & Lincoln, 2005) and researchers were pursuing a range of paradigms and methods (Ireland et al., 2009). Nonetheless, Marton (1981) proposed that the study of variation between phenomena should be a research specialization in its own right, particularly since it was so relevant to questions about learning and understanding in education (Marton 1981). To illustrate his perspective on the matter, Marton (1981) challenged fellow researchers to reflect on the difference between the following research-related questions:

1. Why do some children succeed better than others in school?
2. What do people think about why some children succeed better than others in school?

Marton's reasoning was that "an answer to the first type of question is a statement about reality" (p. 178), whereas an answer to the second type of question is "a statement about people's conception of reality" (p. 178). Furthermore:

> The discerning of these two alternative perspectives has nothing to do with the metaphysical distinction between the real and the apparent, or with arguments for or against as to whether there is a reality as such that is accessible to us. Neither the "realness" of a reality independent of our perception of it, nor the "realness" of our experience of this reality is thus examined and still less questioned here. Our distinction is - we believe – pragmatic and very simple. Following our above example, consider the two statements "The differences in success in school mainly reflect inherited differences in intelligence" and "There are people who think that the differences in school mainly reflect inherited differences in intelligence" Obviously, either of the two statements may be true independently of the other's truth or falsehood. Moreover, we have to do different things in order to verify (or falsify) the two statements (p. 178).

Essentially, Marton (1981) considered that the way a research question is formulated matters. He reasoned that examining a phenomenon, such as a student's success in school, by using a first order perspective, (as per research question 1 above) was different from examining that same phenomenon using a second order perspective (as per research question 2 above). In the first order perspective there would be an emphasis on describing various aspects of the reality of students' success from the point of view of a researcher. In the second order perspective there would be an emphasis on describing various aspects of the reality of students' success from the point of view of the students themselves (Marton, 1981). The critical difference in these points of view is that students' thinking about the aspects of their success is something that cannot be observed (Prosser, Trigwell & Taylor, 1994).

In phenomenography, the researcher seeks to document how the world appears to other people on a collective level (Pang, 2003). The researcher is not making statements about a phenomenon but about people's collective ideas of that phenomenon (Linder & Marshall, 2003; Reed, 2006). Phenomenographers proceed with their research on the basis that there is a finite collection of different yet related ways in which a phenomenon can be conceived and understood (Marton, 1981). As such, learning (which is the pulse of phenomenography) can be seen as the qualitative change in people's conception of reality (Marton, 1986).

Marton's (1986) goal for phenomenography was first and foremost to find and systematize the various forms of thought with which people interpret aspects of the reality of a phenomenon. His initial aim was to develop an empirical research approach directed towards description, analysis and understanding of experiences as they are conceived by individuals (Richardson, 1999). According to Marton (1981):

> All knowledge is rooted in our immediate experience of the world. It is the task of phenomenography to depict the basic structure of our experience of various aspects of reality and to make us conscious of what the world was like before we learned how to see it (p. 40)

Marton's (1981) success with establishing phenomenography as an internationally recognized research methodology can be measured by the number of publications that report its use and/or the use of a methodology informed by the tenets of Marton's phenomenography. While many of these originate in the field of education, (Ashworth & Lucas, 2000; Entwistle, 1997; Harris, 2011; Marton, 2000; Tan, 2009; Sin, 2010; Yates, Partridge & Bruce, 2012), a significant number exist within the disciplines of healthcare

(Wojnar & Swanson, 2007), engineering (Mann, 2006; Daly, Mann & Adams, 2008), computer science (Stamouli & Huggard, 2007) and library science (Yates et al., 2012).

The theoretical framework of phenomenography

Phenomenography is the study of qualitatively different ways in which individuals see, experience or understand things they learn or learn about (Marton, 1981, 2000). Marton (1986) defines phenomenography as "a research specialization that aims to map the qualitatively different ways in which people experience, conceptualize, perceive and understand various aspects of and various phenomena in the world around them" (p. 31).

In phenomenography, the expression "a way of experiencing a phenomenon" means the same as "a conception of a phenomenon", a "way of making sense of a phenomenon", or an "understanding of a phenomenon" (Linder & Marshall, 2003). "Thus variation in ways of understanding, thinking about, conceptualizing or experiencing equate to variation in awareness of different aspects of a phenomenon" (Akerlind, 2008a, p. 242).

According to Alsop and Tompsett (2006), phenomenographic studies are "empirical and non-constructivist" p. 243. They do not set out to describe an objective world independent of individuals. They are distinguished from other research approaches in education in that they are not intended to "produce a model of the capability of humans to learn, perceive and/or behave without reference to a specific context"(Alsop & Tompsett, 2006, p. 243).

Phenomenography makes no assumption about the nature of reality but it does make assumptions about the nature of conceptions, namely that the conceptions held by individuals are linked with their experiences. Conceptions result from human beings thinking about their external world (Svensson, 1997).

The most significant characteristic of phenomenography is its aim to describe conceptions with a view to developing clear interpretation of their structures and relationships. Categories established by a phenomenographic study represent complexities of awareness (Stenfors-Hayes, Hult & Dahlgren, 2013). According to Svensson (1997), conceptions are the central form of knowledge. He notes that:

> The most fundamental assumption is that knowledge and conceptions have a relational nature. Conceptions are dependent both on human activity and the world or reality external to any individual (p. 165).

Barnard, McCosker and Gerber (1999) assign a degree of importance to identifying one's conceptions of experiences. In their opinion, being aware of one's conceptions is being aware of the reality of self. Pratt (1992) describes conceptions as being the specific meanings and understandings that we attach to phenomena which thereafter influence the way we respond to situations involving those phenomena because they act as a lens through which we view the world.

Phenomenographers recognize that there are similarities and differences in conceptions of the experiences of individuals. However, they also recognize that by emphasizing the collective meaning rather than the meaning of any one individual (Barnard, McCosker & Gerber, 1999; Tan, 2009) it is possible to identify and describe the limited number of qualitatively different ways that people understand a particular phenomenon (Barnard et al., 1999; Marton, 1986; Tan, 2009).

A basic ontological assumption of phenomenography is a view of the world from a non-dualistic perspective where the research is not about an object but about the experience between an individual and that object (Marton & Svensson, 1979; Sandberg, 1997; Marton & Pong, 2005). When viewed in this light, “experience can be defined as a relationship between an individual and a phenomenon in the world—a link between the ‘experiencer’ and the experienced” (Linder & Marshal, 2003, p. 273). Human beings and the experiences that they have of the world cannot be seen as separate entities (Kroksmark, 1995).

Barnard, McCosker and Gerber (1999) explain the non-dualistic nature of phenomenography in the following way:

> Just as there are left and right and east and west for direction, so do seemingly antithetical categories taken together constitute the formation of understanding. Conceptions arise from what at first appear to be opposites, for example, experience and thought or fact and illusion. It is important to recognize that of these so-called opposites, one cannot be more or less important than the other; for at any and all times, there are no intermediate stages, boundaries, nor graduations. Thus, it is argued that a conception should not be thought of as either subject or object but both consecutively (non-dualistic). Between the subject and the object, there is a link, a relationship, a tension, an equilibrium (i.e., the object and subject would have no meaning were it not for the other) (p. 217).

From an epistemological perspective, a characteristic of phenomenography is the importance of description for understanding knowledge as a matter of meaning. The assumption is that while there is generality of meaning across objects in addition to similarities and differences in meaning, the generality of meaning is something that has to be explored empirically, not assumed (Svensson, 1997).

The object/subject relationship in phenomenography remains a point of contention for the critics of phenomenography. While all phenomenographers disavow a positivist paradigm that characterizes the world as made up of observable facts that can be interpreted by a researcher in an attempt to find truth, not all phenomenographers agree with a defined paradigm for investigating how humans process and make meaning of experiences (Richardson, 1999). Indeed, while Marton and Pong (2005) uphold the perspective that individuals cannot experience something without there being something to experience, Richardson (1999) believes objects and events exist even if they are not being experienced. Furthermore, while Marton (1981) emphasizes that phenomenographic research uses a second order perspective with the intent of analysis being to depict the thinkers' understanding of that which is thought about (Trigwell et al., 1994), others debate the degree to which researchers can separate themselves from a study participant's viewpoints, thoughts, feelings, intentions and experiences (Ireland et al., 2009).

Concerning factors

Descriptions of methodological limitations are commonplace in any research literature, including in literature about phenomenographic studies. For example, Alsop and Tompsett (2006) take issue with the idea of researcher independence in phenomenography. Their concern is with the data collection process which they describe as being "single pass". This means that all study data is acquired before analysis begins and that researcher influence is limited. It also means that the researcher acquires objective accounts without the underlying idea that in successive interviews an account will be revisited from the researcher's altered level of awareness. In other words,

> Each subject develops their personal understanding of a phenomenon through an unstructured sequence of experiences, but the awareness cannot be observed. All that is collected for analysis by the phenomenographer is a set of individual accounts of similar experiences. Each account is bounded by what the subject is aware of on one single occasion, and this account cannot be interpreted as a limit on either what the individual could be aware of in the future, or, indeed, might have been aware of in the past (p. 253).

In this light, there is a limit to what can be observed in a phenomenographic study because the data collected represents "just one account" from an individual with no attempt to assess whether or not this account is typical for the individual or not; with any one study, phenomenography investigates only the a current, individual explanation of study participants without examining the dimensions of experiences as a formative process (Aslop & Tompsett, 2006).

In a similar sense Stamouli and Huggard (2007) insist that the phenomenon in phenomenographic research cannot be seen in isolation but that there is an "unavoidable relationship between the researcher and the phenomenon that is investigated in any study" (p.182). As such, there is a need to consider the relationship between the phenomenon, the study participant and the phenomenographer. A depiction of this relationship triad is illustrated in Figure 1.

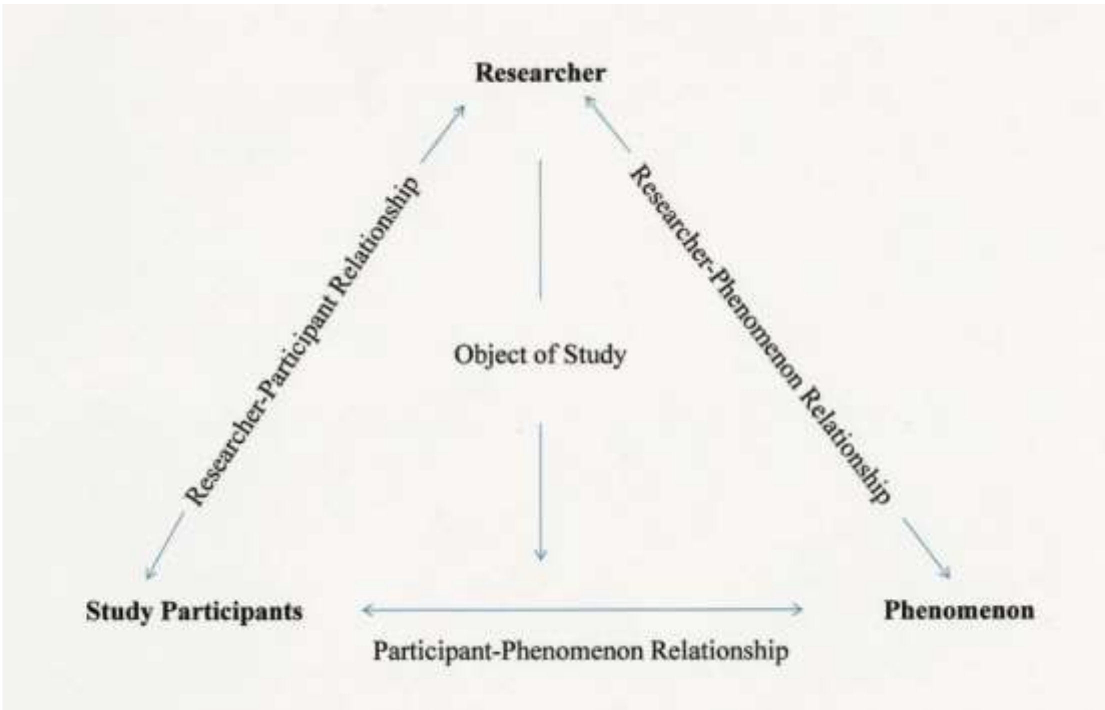

Figure 1: Relationships within a phenomenographic study (adapted from Stamouli & Huggard, 2007)

Eisner (1998) considers the researcher to be an instrument of a study. Therefore, a phenomenographer would be expected to "engage the situation and make sense of it through perception and interpretation of the features that count in a research setting" (p. 32). Eisner considers this a positive use of a researcher's unique background. He elaborates by declaring that the way a researcher uses personal insight to determine meaning is simply one way of providing insight into a phenomenon. It is not a liability but a signature of perception.

Kember (1997) has identified another methodological issue in phenomenography, particularly as it relates to data interpretation and terminology. He notes that:

> In several cases, the terminology for adjacent categories appears to be plausibly interpreted as within the normal variations of alternative phrasing in everyday speech. In interpreting categories it should be borne in mind that even educational researchers often do not define their terminology as rigorously as is the case in many other disciplines and other academics are not a party to the conventions which are established (p. 261).

This concern is particularly relevant in research studies that span academic disciplines such as those that involve biology education at the post-secondary level where phenomenography is not a commonly understood research methodology.

Kember (1997) also notes challenges for phenomenographers with respect to the importance that is placed on describing and naming of categories of description. The descriptions and names of categories of description must be such that they represent all of the ways of understanding that are grouped in a category. When commenting about a description of a conception in terms of a category, Svensson (1997) feels that "the more extensively the role of the general in the specific case is described, the better is the validity and the basis for generalization and theory development" (p. 177). He also feels that phenomenographers must aim at "differentiating the general to be able to find in it the concrete, not to separate it from the concreate as something in and by itself" (p. 177). The concern of phenomenography is to generalize into categories, the conceptions of understanding of a phenomenon that are held by a group of individuals. This reveals the limited number of qualitatively different means or ways of experiencing the phenomenon (Akerlind, 2005a).

Variation theory

In the mid-1990s, phenomenography was criticized for having no guiding theoretical framework (Akerlind, 2005). The basic concern of the qualitative research community was that Marton's (1981) traditional empirical phenomenography of the day aimed to identify only the "what" and "how" aspects of individuals' conceptions of life experiences (Tan, 2009). As such, phenomenography was seen to be a purely descriptive methodology rather than one that could explain why variation in individuals' experiences exist (Bussey, Orgill & Crippen, 2013).

In response to this methodological concern, the attention of phenomenographers shifted towards the development of supporting theoretical and philosophical underpinnings within what was to become known as variation theory (Pang, 2003; Tan, 2009). The central assumption established for variation theory was that learning depends on the variation in learner experiences. To phenomenographers, learning was viewed as a change in the way something could be seen, experienced or understood. The coinciding theoretical position therefore related to learners perceptions of that which is learned and that which could be situated within previous experiences (Akerlind, 2005, 2012). More specifically, according to Bussey et al., (2013):

> The individual's perception of certain critical features based on experienced variation within and between features allows that individual to construct a mental model of a given concept that is unique to that individual. The overall aim of

> variation theory is to explain differences in learning and understanding based on the experience of variation in these critical features (p. 10).

Bussey, Orgill and Crippin (2013) share their perspective on variation being the link between phenomenography and variation theory. More specifically, they posit that phenomenography provides a description of variation and variation theory explains why variation exists. In their words:

> The presence of variation creates a potentially noticeable contrast within or between one or more features of a phenomenon. Take, for example, a series of cartoons in which the only feature that is varied is the size of a particular balloon. The variation in size of the balloon would draw attention to the balloon, and cartoon readers would likely begin to wonder why the balloon was changing size; they would attend to the balloon because of its changing size. At the same time, the readers would most likely ignore many of the invariant features of the cartoon (p. 10).

An additional link between learning and variation is an individual's capacity for discernment (Dahlin, 2007). The experience of variation involves the ability to discern whether or not an object is varied or the same as when it was experienced before. The associated implication is that a person is aware of the critical features of an object or a phenomenon. When a research methodology is informed by both variation theory and phenomenography, the focus is on both the variation among different ways of experiencing something as seen by the researcher and the variation amongst the critical aspects of the phenomenon itself as experienced by the study participant (Pang, 2003; Reed, 2006).

Further along that line of thought about variation theory are the individuals who have ways of seeing that are developed from the ways that they understand their experience (Lo & Marton, 2012). One's way of seeing changes when one learns since one learns when one discerns variation in an aspect of the world. Therefore, variation in an aspect of the world represents an object of learning. Linked to this is the fact that one's past experiences have an influence on the way one sees and understands variation (Lo & Marton, 2012).

According to Dahlin (2007), the concepts of discernment and variation make up the central core of variation theory because one has to discern what is critically different within a phenomenon in order to be able to see that it has dimensions that can vary.

In summary, variation theory augments phenomenography in a specific way. Given that humans each encounter a unique set of experiences and that individuals learn by discernment of variation when they experience something new, variation theory can guide phenomenographers in research studies that encourage reflection as a form of discernment (Bussey, Orgill & Crippen, 2013).

The phenomenography research process

The primary process of data collection in phenomenography.

As is the case in most qualitative research, a critical responsibility of a phenomenographer is data collection. However, unlike in grounded theory research methodology, there is no expectation in phenomenography for the researcher to use a wide variety of data collection techniques. There is no need for immersion of the researcher in the culture of the study as would be the case in ethnography. Participant observation and the generation of researcher field notes are likewise not essential elements (Cope, 2004). Instead, the primary process of data collection in phenomenography is interviewing.

The interview.

A semi-structured, face-to-face, audio-taped interview is the preferred method for data collection in a phenomenographic study (Akerlind, 2011; Ashworth & Lucas, 2000; Bernard et al., 1999; Dall'Alba et al., 1989; Marton, 1981; Marton, 1986; Richardson, 1999). The interview is sometimes task-based (i.e. centered around the participant reviewing a relevant document, listening to an audio file, role playing, etc.) but it is always conducted with the intent of focusing on the relation between the participant and the research object of interest, rather than on the participant or on the research object itself (Reed, 2006).

The phenomenographic interview is viewed as a conversation rather than an inquisition or examination (Alsop & Tompsett, 2006; Ashworth & Lucas, 2000; Brown et al., 2006; Kvale, 1996). A set of questions are asked of each study participant to orient the participant towards the phenomenon of interest and, most importantly, to encourage a process of reflection (Reed, 2006). Furthermore, the primary intent of a phenomenographical interview is collection of the experiences of a phenomenon as described by the individual having the experiences (Reed, 2006). As such, the phenomenographer is first and foremost a listener.

Ashworth and Lucas (2000) believe that the goal of the phenomenographer during an interview is to assist a process of reflection. To that end they suggest that the interviewer should make use of open-ended questions, all of which are carefully prepared in advance. The interviewer should strive to hear meaning, interpretations and understanding and to carefully refrain from interjecting judgement, concern or bias into the interview conversation.

Phenomenographic interviews develop according to the interviewee's response to the semi-structured questions. In some cases, the interviewer probes for clarity of meaning and/or further explanations by asking the interviewee to provide examples and/or additional comments about their conceptions (Akerlind, 2008a). In other cases, the interviewer attempts to explore an interviewee's experiences as thoroughly as possible by following up on the interviewee's comments (Reed, 2006). However, care must be taken to ensure that the researcher refrains from introducing ideas into the conversation that the participant has not already expressed (Ashworth & Lucas, 2000; Yates et al., 2012).

Participant selection.

Generally speaking, participants in a phenomenographic study are selected purposefully (i.e. in a non-random fashion) in an effort to uncover variation to the maximum degree (Patton, 1990; Reed, 2006), or to find informed cases that have potential to augment the in-depth understanding sought by the researcher (Yates et al., 2012). By design, participants of a phenomenographic study are individuals who have experience of the phenomenon being explored. It is the researcher's responsibility to seek out people who have the widest variety of experiences possible but, in doing so, the researcher must avoid presupposition about the "nature of the phenomenon or the nature of the conceptions held by particular types of individuals" (Yates, Partridge & Bruce, 2012, p. 103). Alsop and Tompsett (2006) recommend that the sampling plan of a phenomenographic study be "designed to capture diversity rather than to produce a statistically balanced representation" (p. 244).

Akerlind (2008a) feels that phenomenographic research aims for a range of representativeness of a phenomenon rather than a frequency of representativeness and also that it "aims to discover what is possible rather than what is most common" (p. 243). Phenomenographic research seeks to establish whether or not variation within the study group reflects variation within the targeted population (Akerlind, 2008a).

Sample size.

Sample size in a phenomenographic study is generally determined with a view to allowing a sufficient participant population to uncover varying conceptions about the phenomenon of interest (Patton, 1990; Yates, Partridge & Bruce, 2012). While many qualitative research methodologies seek to reach a point of saturation (i.e. data is collected until no additional conceptions of the phenomenon under investigation are discerned), the perspective of most phenomenographers is that since conceptions are related to a specific context, they are expected to change if the context changes. Therefore, a saturation point might be seen as pertinent to a single context only making the matter an insignificant one in phenomenography (Reed, 2006). Additionally, striving to reach a point of saturation is not necessarily appropriate in a phenomenographic study considering that the end goal is to understand individuals' interactions with phenomena from their own perspective. Reed (2006) supports the belief that there is no way of knowing the extent of the variation that will be captured during the interviews so it is impossible to begin the process with a set plan of how many participants might be required for a level of saturation to be reached. Reed (2006) also points out that because phenomenography seeks to identify variations in all experiences of a phenomenon:

> The best chance of ensuring the complete variation of the ways of experiencing a phenomenon remains to sensibly select the participants in the study to ensure as much variation as possible. It is the collective experience of the participants that is analyzed. An individual is simply a contributor to this collective (p. 7).

According to Akerlind (2008a) a phenomenographer should strive to achieve "the minimum sample that can be expected to show the range of variation that would be present in the population as a whole" (p. 243). Trigwell (2006) suggests that ten to fifteen study participants are needed in order to create a reasonable chance of capturing variation in the range of conceptions.

An additional consideration about sample size is the time consuming nature of the data analysis process in phenomenography given that it involves reviewing transcripts repeatedly and collectively rather than individually and only once (Reed, 2006; Akerlind, 2008a).

Simply put, no matter the sample size, the conceptions revealed in a phenomenographic study remain valid representations of the understanding of a phenomenon because it is impossible to predict whether or not there may be additional ways of understanding that are not represented in the data.

Bracketing.

During the process of determining categories of description within their study data, phenomenographers must focus on the experiences of the study participants whilst bracketing preconceptions based upon their own experiences of the domain in question (Marton, 1986).

Bracketing refers to the need for the researcher to set aside his or her own assumptions so far as possible in order to register the interviewee's own point of view. The purpose of bracketing is to avoid judging the extent to which responses from an interview reflect an understanding of the phenomenon being studied similar to that of the researcher and to focus instead on the similarities and differences between the ways the participants conceive their experiences of the phenomenon (Ashworth & Lucas, 2010; Sandberg, 1997).

Ashworth and Lucas (2000) caution phenomenographers to be conscious of anything that would lead the interview process away from careful listening about the participants' experience. They list the following as the kinds of presuppositions that must be bracketed by phenomenographic researchers:

- importing earlier research findings
- assuming pre-given theoretical structures or particular interpretations
- presupposing the investigator' s personal knowledge and belief
- ignoring any pressure to uncover the `cause' of certain forms of student experience.

Sandberg (1997) cautions phenomenographers to maintain an interpretative awareness by acknowledging and explicitly dealing with any potential preconceptions that might influence the research process, particularly data analysis. Interpretative awareness helps avoid the habit of focusing on statements that support a researcher's own opinions or selectively interpreting statements so they can justify the researcher's own conclusions while ignoring statements to the contrary (Kvale, 1996).

However, while avoidance of researcher preconceptions is important in phenomenography, the methodology accepts that the relationship between a researcher and the phenomenon being researched is one in which the researcher requires a knowledge and understanding of all aspects of the phenomenon so as to be able to discuss and query study participants in an informed manner (Stamouli & Huggard, 2007). This researcher-phenomenon relationship is especially important during the development of the outcome space because it "allows the phenomenographic researcher not only to list people's conceptions in the form of categories of description but also the researcher's interpretation of the relationship between them" (Harris, 2008, p. 65).

Data analysis.

Phenomenographic researchers report various approaches to data analysis (Ashworth & Lucas, 2000; Reed; 2006; Richardson, 1999; Walsh, 1994; Yates et al., 2012). "The classic formulation of the phenomenographic method of Marton" (Reed, 2006, p. 7), referred to by many as "pure phenomenography" (Akerlind, 2005; Alsop & Tomsett, 2006), suggests that the phenomenographer undertake the following steps to complete the process of data analysis (Alsop & Tomsett, 2006; Larsson & Holmstrom, 2007; Marton & Booth, 1997; Marton & Saljo, 1984; Stenfors-Hayes, Hult & Dahlgren, 2013):

1. Read the interview transcripts several times, each time giving all aspects of the interview equal consideration and each time exploring a new perspective or focus. Evaluate responses juxtaposed with the study's research questions as well as with the interview questions that were asked. Select passages within the transcripts where interviewees have reflected on their experiences of the phenomenon being investigated. Consider the entire collection of transcripts rather than individual transcripts. Identify similarities and differences between the transcripts.
2. Cut out sections from the interview transcripts that relate to the participants' conceptions of their experiences of the phenomenon to form a pool of meanings (i.e. a collection of utterances or quotes which are also referred to as meaning units). Retain a focus on the context from which the utterances came. The pool of meanings represents all of the possible ways of experiencing the phenomenon in question including the non-dominant ways of understanding the phenomenon.
3. Develop a limited number of internally and logically related, qualitatively different, hierarchical categories of description to represent and organize the variation in the way the phenomenon is experienced (this will involve sorting and re-sorting the meaning units until the categories emerge from the data in a stable way). Be prepared to illustrate each category of description with representative quotes from the pool of meanings.
4. Constitute a structured outcome space from the categories of description. Represent the outcome space graphically to illustrate the hierarchy and/or relationships of the categories of description.

The analysis process depicted in these four steps involves the phenomenographer identifying meaning depicted in the qualitative similarities and differences across the transcripts. As such, phenomenographers do not concern themselves with the richness of data within transcripts to the degree that researchers do when using other qualitative research methods (e.g. phenomenology). Instead, the focus of a phenomenographic study is on examining transcripts for clear evidence of variation. Further to this point, Mann (2006) believes that if a phenomenographic analysis focuses instead on data richness or "every nuance of meaning" (Akerlind, 2005b), the structural relationship depicted within the outcome space of a phenomenographic study would not be possible to the same degree as when evidence of variation is the main facet of the analysis. Similarly, with respect to the matter of rich data in transcripts, Stenfors-Hayes, Hult and Dahlgren (2013) note that:

> Each person's experience is unique, but a descriptive collection of such unique conceptions is considered less useful, when it comes to guiding educational change, for example, than the related categories and their critical variation that a phenomenographic analysis provides. This means that the descriptions in a phenomenographic study are less rich or "thick" when it comes to describing a certain person's way of understanding than in a phenomenological study" (p. 266).

For Cope, (2004), the result of a phenomenographic study is a hierarchically ordered set of sparse descriptions rather than a flat structure of rich descriptions.

Categories of description.

In the data analysis process, a phenomenographer looks for groups of quotes across the study's transcripts that logically link together as a collection of themes, referred to as themes of awareness, which describe different ways of experiencing a phenomenon. Each collection of themes of awareness is referred to as a category of description. When grouped together, categories of description "provide a way of looking at collective human experience of phenomena holistically despite the fact that the same phenomena may be perceived differently, by different people, under different circumstances" (Akerlind, 2005a, p 323). Marton and Booth (1997) refer to categories of description as a collective level of variation.

The outcome space.

The outcome space represents the completion of a phenomenographic study (Alsop & Tompsett, 2006). It is an inclusive structure that depicts a relationship between categories of description. It is a comprehensive depiction of the "how" (the structural) and the "what" (the referential) aspects of conception and understanding. Marton (1986) describes it as an empirical map of people's experiences with a phenomenon which is arrived at if the researcher moves beyond simply recording the different ways participants talk about the phenomenon to delving behind what is said in the effort to organize how a phenomenon is understood (Walsh, 1994).

Marton and Booth (1997) use three primary criteria for judging the quality of an outcome space:

- each category reveals a distinctive facet of the conceptions held about a phenomenon

- the structure depicts a logical relationship of the categories description
- there are as few categories of description as possible to represent the variation in experience revealed in the data

Phenomenographers hold varied opinions on the actual structure of a study's outcome space. Stamouli and Huggard (2007) note that since the categories of description in a phenomenographic study represent a range of understanding, they should be illustrated as a hierarchy. On the other hand, while Akerlind (2008a) agrees that the outcome space is a representation of "inclusivity of awareness" (p. 243), she takes issue with the emphasis placed on a linear hierarchy of understanding. Instead, branching structures are also a possibility, in her opinion. An outcome space depicted thusly would illustrate variation in conception that does not appear to form part of a logical relationship between categories of description (Akerlind, 2008a).

No matter the structure of the outcome space, most importantly, it must "represent all possible ways of experiencing the phenomenon in question, at a particular point in time, for the population represented by the sample group" (Akerlind, 2005, p. 323).

With respect to the outcome space including the "cause and effect" aspect of conceptions, Ashworth and Lucas (2000) note that despite it being a valuable component of meaning of an experience and one that should be heard by the researcher, a study participant's assumptions about why they have had certain experiences is a distortion of the experience description and should be thought of that way by the researcher. Phenomenography is not about identifying cause. It is about describing an experience not explaining why an experience is what it is (Yates et al., 2012).

A final consideration of the outcome space of a phenomenographic study is that it is typically presented graphically in the form of a diagram, figure, chart or table. These are usually accompanied by descriptive commentary and occasionally, as metaphors (Larsson & Holmstrom, 2007; Reeves, 2014).

Research quality

Morse et al., (2002) advocate for the use of careful and thorough qualitative research procedures so that validity and reliability of the results can be assured. Research validity is, in essence, consistency within the research approach. Reliability of research is a measure of its trustworthiness. Both of these measures of research quality are recognized by phenomenographers as being important aspects of the work they do as researchers. For that reason there is value in exploring each of them more extensively here.

Validity.

Sandberg (1997) proposes that the places where validity is relevant in the phenomenographic process include the interview and the analysis process. Lewellyn, Dall' Alba and Radcliffe (2007) suggest that a researcher consider implementing the following actions as a way of acknowledging that validity of one's research is critical:

- establish communicative validity by informing interviewees of the intent of the interview so as to develop a joint understanding between the subjects and the researchers about what was being discussed.
- explain that there are no right or wrong answers so as to clarify that no judgements will be made of the participant by the researcher.

- focus on the transcripts as wholes, rather than trying to extract parts of the transcripts and analyze them out of context.
- look at the similarities and differences between whole transcripts as a way of acknowledging that when a particular statement is taken out of the transcript it may appear to fit into one category, but when it is seen within the whole transcript it fits into another category.

Reliability.

Sandberg (1997, 2005) suggests that reliability in a phenomenographic study revolves around the researchers' degree of control of the research process. Llewellyn, Dall'Alba and Radcliffe (2007) feel that this control begins at the point of formulating the research questions. More specifically they insist that the researcher needs to pose questions that focus on exploring ways of experiencing a phenomenon rather than on confirming a preconceived perspective. As well, there is a need for the researcher to acknowledge that the potential for their own experiences to influence various parameters of the study. This is best accomplished when the researcher provides an accurate and detailed account of the research process (Alsop & Tompsett, 2006).

Then there is the selection of study participants which should be done with the intention of representing the broadest range of experiencing the phenomenon rather than what the researcher believes the phenomenon is.

This is followed by efforts to make interview sessions as similar as possible with respect to the open-ended questions asked and the prompts used. At the minimum each interview should start with the same orientation information and the same initial question and then end with the same concluding question and remarks of appreciation.

Interviewers should also aim to refrain from their habits (commentary, body language, attempts at rebuttal) influencing the interviewee in any way. Marton and Pong (2005) acknowledge that there is potential for conceptions to be made unstable depending upon the attitude of the interviewer. They feel that study participants might be tempted to change their answers and even contradict themselves based on the way they interpret the researcher's prompts and responses to the comments of the interviewee.

Finally, there should be a strict respect of the data in the interview transcripts so that statements remain in context (Llewellyn, Dall'Alba & Radcliffe, 2007). The researcher must accurately reproduce the expressions of the study participants, not only to generate trust from readers but also to "offer a choice to the reader whether to accept the interpretation of the researcher or to question, re-interprets or reject the researchers analysis" (Osteraker, 2002, p. 4).

Why is phenomenography an appropriate methodology for this study?

As is the case with all "pure phenomenography" research, my study aimed to understand the conceptions that individuals (in this case academic biologists) have of their experiences with a phenomenon (in this case biology education) without an effort to find out why those varied conceptions are what they are or why they happened. Phenomenography is research from a second order perspective so the focus of my investigation was the experiences from the biologists' perspectives rather than from my own. It was the biologists who made statements about biology education rather than me.

I studied what the biologists told me about biology education. I described biology education as it appeared to and had been experienced by the academic biologists in my study group (Marton & Pong, 2005). I was not intending to examine the phenomenon directly but through the various ways that it is experienced by others. This made it necessary for me to avoid a methodology that was from a first-order perspective (such as phenomenology) where a researcher studies a phenomenon directly in an attempt to describe things as they are, the reality of biology education, in this instance (Giorgi, 1999; Marton, 1981,1986; Marton & Pong, 2005; Prosser et al., 1994; Trigwell, Prosser & Taylor, 1994; Yates, Partridge & Bruce, 2012).

By using a phenomenographic approach, the nature of the outcome of my study was intentionally meant to be different from other qualitative approaches. As described by Cope (2004), a phenomenographic study's identification of a sparse set of hierarchically order, distinctly different ways of experiencing a phenomenon is a departure from other qualitative approaches that produce richly descriptive outcomes of a flat structure. Rather than aiming at developing a single theory of experience, as would be the case if I was using a phenomenological research methodology, for example, the focus of my phenomenographic research was the architecture (i.e. hierarchical structure) of the variation in other people's experiences of the phenomenon of biology education.

Given my research intentions, phenomenography was an appropriate methodology for my study because of its "usefulness for revealing how things look from the point of view of the respondent" (Pratt, 1992, p. 204). Phenomenography seeks to identify variation amongst broad categories of conceptions but it does not attempt to explain what it is that brought those conceptions about. As well, phenomenographic data analysis involves a researcher/data relationship that acknowledges the "undeniable influence of the researcher's prior knowledge of the phenomenon in the analysis process" (Cope, 2004, p 7).

In my case, phenomenography allowed me to identify variation amongst the conceptions of academic biologists about biology education through awareness of my own experiences with biology education. Essentially, through the process of completing my study, phenomenography allowed me to develop a relationship with my data based on my own experiences with biology teaching and learning. Indeed, phenomenography expects that the researcher has an in depth knowledge of the phenomenon being researched (Stamouli & Huggard, 2007).

The process of completing my study also allowed me to generate an outcome space that could be "used to develop generalizations about better and worse ways to organize learning experiences in biology" (Bowden, 1994, p. 5). This means that through a phenomenographic study about academic biologists' conception of biology education, I could reveal an outcome space that would allow me to generalize about the better and worse ways of organizing secondary biology curriculum.

The research process for this study

In the remaining sections of this chapter I will present my research process, the basic steps of which are itemized in Table 1. Stenfors-Hayes, Hult and Dahlgren (2013) suggest that "a detailed description of all steps of the research process (including the interview protocol and details on decision made in the analysis) increases credibility" (p. 267). I considered this to be good advice, given that this was the first time I had conducted a phenomenographic study independently. Therefore I will provide in-depth information about each step of my methods. I believe that this attention to detail will not only increase the quality of my work but it will help readers understand how I interpreted the advice of researchers, who are experts in this qualitative research approach, about how to do phenomenography.

Research Process For This Study	
Data Collection	**Data Analysis**
Development of interview questions and processes	Transcripts read while audio-tapes of interviews were played
Identification of study participants	Transcripts read repeatedly and with different foci
Distribution of invitation letter	Meaning units (utterances) identified and labeled
Completion of consent forms	Similarities and differences between meaning units noted across all transcripts
First interview conducted	Pool of meanings formed from meaning units
Second interview conducted	Pool of meanings organized iteratively into categories of description; name and description of each category developed from collections of themes of awareness found in the pool of meanings
Interviews transcribed	Outcome space constituted including referential and structural aspects of the categories of description

Table 1: The research process for this study

Data collection for this study

Development of interview questions and processes.

I implemented the methodology for my study through the context of two separate semi-structured interviews using a series of questions that were intended to encourage my study participants to reflect on their life experiences with biology education. The questions in both interviews were meant to stimulate academic biologists to talk about themselves and their conceptions of what it is to be a biology student, what it is to be a biology teacher and how those conceptions are relevant to being a biologist who does biology and teaches biology at a university. Interview one questions are presented in Appendix I. Interview two questions are presented in Appendix II.

The development of my interview questions proceeded through several draft phases. While generating these drafts I aimed to frame my queries such that they would be clearly understood by the interviewees. As would be expected in a phenomenographic study, I asked questions from a "what" and a "how" perspective but not from a "why" perspective. I relied on my own understanding of biology education for this purpose but I retained awareness of the need for to avoid weaving in my own preconceptions and personal bias.

Once I had developed the final version of my interview questions, I prepared the information that I intended to share with all study participant at the start and end of each interview session. My goal was to have the interviews proceed as consistently as possible so I used the same introductory explanations and the same concluding remarks for each one (Mann, 2006).

Questions for interview 1.

To encourage the interviewees to think about the education pathway they had followed to become an academic biologist, I planned for the first interview to begin with questions (#1, #2, #3) that would reveal personal understanding of their studies and work. Those questions were to be followed by others (#4, #5, #6, #7, #8, #9) that I intended to spur study participants to think more specifically about: what studying biology meant to them; what teaching biology meant to them; how they would represent biology teaching excellence. Thereafter, as a precursor to the second interview, the main focus of which would be secondary biology education, I developed a question (#10) that asked them to reflect upon their views on biology teaching excellence at the university level as compared with biology teaching excellence at the high school level.

The final question of interview one (#11) was meant to provide the opportunity for study participants to comment further about anything that we had already discussed or about anything that our conversation had brought to mind after the fact. My decision to conclude the interview this way was based on past experiences with qualitative interviewing where I found that interviewees abruptly stopped talking when I mentioned that we had covered all of the questions that I had planned to ask in the interview. Additional talk was not offered spontaneously, but inevitably, after the tape recorder was shut off, interviewees would confess that they wished they had said something else that had just come to their minds. Turning the audio recorder back on wasn't the answer to this circumstance I found because it tended to rekindle a nervousness that more often than not was commonplace at the beginning of each interview and which lasted until interviewees became so involved with their reflections that they forgot that their words were being recorded.

Questions for interview 2.

The questions that I developed for the second interview were based on tasks that I asked each study participant to complete either between the interviews or during interview two. Task 1 was to be completed between interviews. It required the study participants to review a paper copy of the high school biology curriculum document that I had provided them with when the first interview was finished. The questions in interview two that were specific to Task 1 (i.e. questions a-h) were intended to probe academic biologists' awareness and understanding of the development and implementation of secondary biology curricula.

Task 2 was completed during the second interview. It required the study participants to consider a single curriculum component (a learning outcome from the New Brunswick 122 biology curriculum) while imagining themselves as high school biology teachers. I intended the question that was specific to Task 2 (i.e. question i) to be one that allowed me to gather the views of interviewees about the teaching actions that a high school biology teacher would be expected to undertake.

Task 3 was also completed between the two interviews. It required the study participants to provide me with a syllabus for one of the university biology courses that they taught. I intended the questions that were specific to this task (i.e. questions j-k) to be ones that allowed me to probe interviewees for their conceptions of the decisions they make when developing their own course curricula.

As was the case with the final question of interview one, I intended for the last question of interview two (i.e. question l) to provide the opportunity for study participants to comment further about anything that we had already discussed in either interview or about anything else that our conversations had just then brought to mind.

Identifying and registering participants of this study.

My quest for study participants was based on a purposeful sampling approach (Patton, 1990) and on an intention for the participants of my study to represent a broad cross-section of disciplines within the world of academic biology (Yates, Partridge & Bruce, 2012). The criteria that I used to guide my participant selection process included areas of specialization (in biology teaching and research), levels of experience, gender, age range and classification level (appointment status at their university). With these diversity criteria in mind, and the awareness that ten to fifteen study participants can be expected to adequately represent the variation of experience with a phenomenon (Trigwell, 2006; Akerlind, 2008a), I identified twenty-five academic biologists from across Canada through credentials presented about them on their respective university websites. I hoped that amongst this pool of potential participants there would be a sufficient number willing to be part of my study. I sent invitation letters to all twenty-five individuals via email and received positive responses from eleven of them. These academic biologists, from seven university biology departments, then became my study group.

I have organized the details of participant demographics in Table 2. A copy of the invitation letter is presented in Appendix III along with a copy of the consent form that each study participant was asked to sign before the interviews began.

Participant Code	**Biology Specialty**	**Career Span**	**New Brunswick Biology Curriculum Document Reviewed**	**Interview Mode** (participant preference)	
				Interview 1	**Interview 2**
P01	Physiology	37	Biology 112/111	Skype	Skype
P02	Genetics	20	Biology 122/121	Skype	Telephone
P03	Biochemistry/ Microbiology	19	Biology 112/111	Face to Face	Telephone
P04	Mycology	40	Biology 112/111	Face to Face	Skype
P05	Systematics/ Evolutionary Biology	23	Biology 112/111	Face to Face	Face to Face
P06	Plant Ecology	10	Biology 122/121	Face to Face	Skype
P07	Mycology	25	Biology 112/111	Face to Face	Face to Face
P08	Botany	19	Biology 112/111	Face to Face	Face to Face
P09	Ornithology	20	Biology 112/111	Face to Face	Skype
P10	Fish Biology	18	Biology 112/111	Face to Face	Face to Face
P11	Landscape Ecology	35	Biology 112/111	Telephone	Telephone

Table 2: Participant demographics

Interviews with my study participants.

Each one of my study participants was interviewed twice, through a mode of their choosing: a face to face manner in their preferred location; via Skype; during a telephone conversation; through a combination of modes. Arrangements about the time and date of the interviews were set so as to be convenient for the participants. The interviews were between forty-five and sixty minutes in duration and they were all completed within a three month period of time.

Before I turned on the audio recorder for each interview, I took time to express my appreciation for the individual's willingness to talk with me and I then clarified the various aspects of the endeavour that the study participant and I were about to undertake. I noted that we would be proceeding through a set number of questions and that while I was very interested in the interviewee considering us as having a conversation, my primary role was that of a listener rather than a co-conversant. I made it clear that I would not be giving my own answers to the questions nor would I be offering any rebuttal to what I was hearing. In essence then, I politely let the study participant know that although the interview would not be a dialogue, my minimal part in our time together in no way represented disinterest. Rather, it was the approach specified by my chosen methodology. It was meant to allow the interviewee to be free to respond without any influence from me. I also pointed out that there were no right or wrong answers to any of the questions, just the answers that the interviewee chose to provide. After this introduction, I turned on the tape recorder and asked the first question.

During interview one, all of the academic biologists were asked the same questions following the same question order. The interviewees were encouraged to respond to each question as they saw fit. I endeavored to listen in such a way that they would feel no pressure or embarrassment if they hesitated before beginning to answerer or if they paused for a length of time at any point in the delivery of their answers. Phenomenographers often use phrases such as “would you be able to give me an example of that” or “can you explain that further” after interviewees have ended their response to a question (Akerlind, 2005a). This is perceived as a way of probing for underlying meaning, for additional information or for clarification. It is also perceived as a way to ensure that the conversation between the researcher and the respondent continues until there is mutual understanding between the two (Stenfors-Hayes, Hult & Dahlgren, 2013). I seldom followed this practice because I found that my study participants more often than not indicated to me that they took this action to mean that I found their initial answer insufficient. I also believed that probing was uncalled for because it was obvious that my study questions were clear to my study participants. Likewise their answers were clear to me. This validated the time that I had spent in developing the research questions. It also revealed and confirmed for me the accuracy of Stamouli and Huggard’s (2007) description of the boundaries of the researcher- participant-phenomenon relationship as discussed earlier in this chapter.

I have included details of the interview mode that I arranged with each participant in Table 2 as well as a clarification of which curriculum document each participant was given to review between interviews. These curriculum documents were distributed randomly.

Transcription of the audio-taped interviews.

I audio-taped the interviews and then transcribed them myself. I made the conscious decision to edit out pauses and sub-vocals from the transcriptions at the suggestion of Diamond (2007) and Reed (2006) who share the opinion that data analysis in phenomenographic studies should focus on content and eliciting meaning. As such, transcripts of phenomenographic interviews are not concerned with the sociolinguistic aspects of an interview that are of basic concern in discourse analysis research methodologies. This perspective is also shared by Barnard, McKosker and Gerber (1999) who note that the interview transcript in phenomenographic studies is meant to emphasize "the content of description rather than the language used" (p. 223). My transcriptions were therefore intent on collecting and transferring to text format, all content-related dialogue.

Data analysis for this study

I treated the audio files and the corresponding transcriptions as data and analyzed them collectively after all of the interviews were completed. The analysis process that I used is explained in the next sections.

Reading and re-reading the study transcripts.

To begin the analysis of the interview transcripts I read each of them for the first time while listening to the related audio files. This action served to engage my memory of the actual interviews. What had gone dormant in my mind after the interviews had been completed, about my study participants' views and claims, returned to my consciousness in a way that it hadn't while I was immersed in the role of a transcriber.

I thereafter read the transcripts four additional times, each time from a different perspective, to search for clarification of what my study participants were meaning by their responses to the interview questions. As suggested by Marton (1986) and by Stenfors-Hayes, Hult and Dahlgren (2013), I considered each reading of the transcript as a new experience. Each reading provided an opportunity for me to look at the data differently. Marton and Booth (1997) refer to these successive readings of interview transcripts as cycles of reading through which the researcher should attempt to concentrate on one variant of understanding per cycle. Therefore, when I read the transcripts a second time, I focused on and highlighted the passages that represented the interviewees' conceptions of teaching biology. When I read the transcripts a third time, I focused on and highlighted the passages that represented the interviewees' conceptions of learning biology. During the fourth reading of the transcripts I searched for and highlighted passages that represented the interviewees' conceptions of doing biology. During the fifth reading of the transcripts I focused on similarities and differences of meaning across the transcripts collectively.

Through all of these cycles of reading, I concentrated on being open to the facets of the data that would allow me to distinguish the range of variation of conceptions held by academic biologists about biology education. I constantly reminded myself that "no one interview transcript can be understood in isolation from the others" (Akerlind, 2005a, p. 325).

Identifying and labelling the meaning units of this study.

After the repeated reading of the transcripts, I was left with a series of highlighted passages in the transcripts. Essentially these were selected comments from all of the interviews. They were occasionally single sentences but usually longer excerpts from the transcripts. I assigned a locater label to each quote, so as not to lose the passage from the context in which it was first made and so that I could return to where the quote originally emerged from a transcript if need be. I then transferred all of the selected quotes, through cut and paste word processing, to a unique text file. This step served to "decontextualize" the quotes (Akerlind, 2005a; Reed, 2006). From that time forward, I used the terms "quote", "participant utterance" and "meaning unit" interchangeably. The collection of meaning units formed my study's pool of meanings (Marton, 1986; Reed, 2006).

Preparing the descriptions of categories.

After printing the pages of the text file of my study's pool of meanings, I physically cut all of the meaning units away from the pages and started the process of grouping the resulting paper strips on which the meaning units were found. While I was doing this sorting and re-sorting, I reminded myself to consider the "what" and the "how" aspects of understanding the phenomenon I was investigating (i.e. the structural and referential aspects of it). At the suggestion of Bowden (1994), I continually asked myself two different questions: what are these quotes saying about biology education; how are these quotes expressing the meaning and understanding that academic biologists have of biology teaching and learning? Also, while sorting and re-sorting the meaning units of my study, I looked for similarities and differences of meaning. As detailed by Akerlind (2008b), I was searching for what was noticed and not noticed by my study participants about the phenomenon of biology education.

I formed fourteen different groups or categories of meaning units after the first sorting. The reality of this meant that I had fourteen piles of paper slips on each of which was printed a meaning unit. For each of these categories, I developed a detailed description. The writing of these descriptions required me to find a way to include the collection of themes, which I thereafter coined "themes of awareness", that I had found in the meaning units of the category. The relationship between the themes of awareness within a category represented the dimensions of understanding that were revealed within that category. The relationship between the themes of awareness within a category also provided the rationale for the name that I gave to the category. That name had to represent all of the themes of awareness within the category. After I had written the category descriptions and had chosen the category names, I selected representative quotes from my study's pool of meanings to illustrate each category.

At this point I recognized that the grouping aspect of phenomenographic data analysis is truly an iterative process because while similar meaning units could be contained within a definable category and the differences between categories were quite obvious, at the end of the first sorting, there were meaning units that didn't fit within any of the fourteen groups that I had initially established. I referred to these as outlier meaning units because at the time I was unable to clearly articulate a description and name for a category that could encompass them. But in phenomenography, "every statement is of equal value, independent of the number of informants sharing it"

(Osteraker, 2002, p. 5), so these outlier meaning units could not be ignored. I therefore needed to re-group and once again develop descriptions and names for the new categories that emerged. To do this I went back to searching through the themes of awareness in the meaning units to find a way to look at them in a different light.

In the end, I re-grouped the meaning units and developed associated category descriptions many, many times. During these iterations, I created a reference chart to remind me of what I needed to be conscious of each time I reorganized my study's pool of meanings in to categories. This reference chart kept me consistent throughout my cycles of analysis. It looked like this:

Group of similar meaning units (collection of themes of awareness) = Category

Description of the collection of themes of awareness = Name of category

Relationship between themes of awareness in a category = Dimension of awareness within category (i.e. degrees of complexity)

Representative quote(s) from the pool of meanings = Illustration of the category's degree of variation

I proceeded through the iterations of my analysis realizing that it was not only important for me to completely contain the entire pool of meanings within the categories of description for my study, but that is was also necessary for me to identify the least possible number of qualitatively different, logically related categories to represent the entire pool of meanings (Marton & Booth, 1997; Alsop & Tompsett, 2006). The final categories of description that emerged from my data were the ones that survived through the full analysis albeit with their descriptions and names modified significantly through the various iterations (Trigwell, 1994).

To review, in the process of identifying the final categories of description of my study, I focused on the collection of themes of awareness from a group of meaning units. Each collection of themes of awareness constituted a category. I wrote descriptions of these categories that reflected the dimensions of meaning within each category. I created a name for the category by giving consideration to these descriptions. I selected meaning units (i.e.quotes) that represented the description and name of each category.

Through sorting and re-sorting of the meaning units and by writing and re-writing the associated descriptions, I was finally able to establish a stable set of named categories of description. I considered stability within the categories of description to mean that the categories represented the data accurately and inclusively and that they would be recognizable by members of my study group even if they didn't all represent the understanding of any one individual at any point in time (Akerlind, 2005a). Marton (1986) describes the stability of categories of description in the following way:

> An important difference between [phenomenographic analysis] and traditional content analysis is that, in the latter case, the categories into which the utterances are sorted are determined in advance. …the phenomenographic process is tedious, time-consuming, labour intensive, and interactive. It entails the continual sorting of data. …descriptions for categories [are not pre-determined but] are tested against the data, adjusted, retested and adjusted again. There is however, a decreasing rate of change and eventually the whole system of meaning is stabilized (p. 42).

Constituting the outcome space of this study.

The constitution of the outcome space was the last step in my research process. I considered it as the final phase of data analysis and the stage that required me to organize my study's categories of description (Bowden, 1994: Trigwell, 1994; Cope, 2004) in a relational way.

While planning the structure of the outcome space, I was conscious of the fact that in phenomenography, a category of description represents a conception of a phenomenon; a way of understanding a phenomenon; a way of experiencing a phenomenon; the meaning ascribed to a phenomenon. No one conception is more important than another, but one conception can depict a more or less inclusive awareness of meaning of the phenomenon within the study group. It is the collection of categories of description in an outcome space that represent the variation in all the different conceptions of the phenomenon (Marton, 1986; Reed, 2006).

To identify the hierarchy represented by the categories of description in my study, I relied completely on the collection of themes of awareness for which I had written detailed descriptions for each category. Because I considered that variation in the breadth of understanding of biology education could represent a degree of complexity, the category of description that showed a greater breadth of understanding was the one that I placed at the pinnacle of the hierarch in the outcome space. The categories of description that represented increasingly less complex understanding were placed at progressively lower levels in the hierarchy.

I sought examples of outcome space designs from other phenomenographic studies. I was influenced by the work of Boulton-Lewis et al., (2001) and the work of

Marton and Pong (2005) and therefore decided to present my study's outcome space in table format and as well as in a diagrammatic format. I believe that these two formats augment each other to reveal the results of my research.

Attention to research quality and ethics.

Through all of the parameters of my study I respected the need for validity and reliability according to the recommendations about research quality that are outlined earlier in this chapter (see pages 57-59). I also adhered to the research ethics parameters of my study as they were approved by the University of New Brunswick.

Concerns about researcher influence in this study's data analysis process.

In several of the stages of the research process for this study, I had to decide on forward steps. For each occasion I paused to evaluate how significant an influence my own experiences with, and conception of biology education were apt to be in my decision making.

Most often it was impossible for me to predict any degree of influence that could invalidate my work. For example, when I was conducting the interviews with my study participants, I was usually asked to describe my background at some point during the conversation. When this happened, I answered as generally as was socially acceptable to do but I wondered whether or not the information my response revealed about me as a biologist and biology teacher would have any influence on the interviewee. Similarly, even with my awareness of the need for bracketing, I felt it necessary to draw on my own knowledge of biology teaching and learning each time I wrote a description for a category. Was this a form of researcher bias? I thought not based on Akerlind (2005a) noting that the outcome space of a phenomenographic study inevitably reflects both the data and the researcher's judgments in interpreting that data. In her opinion it is widely understood that the interpretive process in a phenomenographic study represents the very personal nature of the researcher's experience with the data.

A final example of where I felt there was potential for unintended influence on my part was when I relied on my background to decide what the categories of description were telling me about the levels of complexity within academic biologists' conceptions of teaching and learning biology. My concern here was assuaged by Walsh (1994) who believes that it is impossible to come to anything without preconceived ideas and that if phenomenographers set aside everything they know about a phenomenon they would not be able to make sense of anything that people are telling them about it.

In the end, I worked through my concerns about researcher influence to complete the analysis of my study's data in as accurate and as unbiased a way as possible. Having acknowledged this, I will now move on to the next chapter in which I will present the findings of my study including the descriptions and names of the categories as well as well as the two different formats of the outcome space.

Chapter 4 Results

> To discern an aspect is to differentiate among the various aspects and focus on the one most relevant to the situation. Without variation there is no discernment. We do not think in a conscious way about breathing until we get a virus or walk into a smoke-filled room. Learning in terms of changes in or widening in our ways of seeing the world can be understood in terms of discernment, simultaneity and variation. Thanks to the variation, we experience and discern critical aspects of the situations or phenomena we have to handle and, to the extent that these critical aspects are focused on simultaneously, a pattern emerges. Thanks to having experienced a varying past we become capable of handling a varying future (Bowden & Marton, 1998, p. 7).

To help the reader navigate this chapter, I will begin it with a generalization of the findings of this study. After that I will move to the specific components of my results.

Generalization of the findings of this study

This study's outcome space is inclusive of six categories of description. Three categories express academic biologists' understanding of biology teaching: Category CT1 - Biology teaching is bound by the discipline-based curriculum and related pedagogy; Category CT2 - Biology teaching varies within levels of the education system; Category CT3 - Biology teaching is an extension of academic biologist's own experiences with biology as a study subject, as a science discipline and as a career. Three categories express academic biologists' understanding of biology learning: Category CL1 - Biology learning results from doing biology through preferred process and place; Category CL2 - Biology learning is related to the person who guides or mentors the student; Category CL3 - Biology learning is multiple discovery related to circumstance and opportunity.

A word about the organization of the findings of this study.

Organizing the findings of a phenomenographic study so that it is possible to see how they clearly answer a researcher's guiding questions is challenging because of the large quantity of data that are generated through the research process. Phenomenographers present meaning units (quotes) as components of their results and when a study produces large numbers of them, their interspersion with the findings can inadvertently cause the reader to become disoriented. Also, there is a tendency for the reader to try to identify features of the quotes rather than to focus on the way the quotes are similar and different. As well, the reader must remember that in phenomenography, quotes are decontextualized (i.e. during analysis they are removed from the context in which they were initially uttered) and that they are meant to represent the understanding of the group as a whole rather than one individual in the group.

Recognizing these challenges, I wanted to introduce a logical transparency to my study's findings so that the reader could relate to how I generated them from the data. To that end, the first results presented in this chapter will be the descriptions of the collections of themes of awareness from which were generated the study's categories about biology teaching. These descriptions will appear as a succession of paragraphs interspersed with representative quotes. The categories will each be summarized through what I determined to be their referential and structural aspects.

The next results presented in this chapter will be the description of the collections of themes of awareness from which I generated the study's categories about biology learning. These descriptions will also appear as a succession of paragraphs interspersed with representative quotes. The categories will also be summarized through their referential and structural aspects.

The last results presented in this chapter will be the outcome space. The tabular form of the outcomes space will include illustrative quotes representing the referential and structural aspects of the categories of description while the diagrammatic form will illustrate the hierarchy of the categories.

Categories of description about biology teaching (CT1, CT2, CT3)

Category T1 – Biology teaching is bound by discipline based curriculum and related pedagogy.

Five different collections of themes of awareness informed the description of this study's first category pertinent to biology teaching (Category T1). Based on their primary focus, these themes are:

Category T1 – Themes of awareness collection A – Curriculum development

Category T1 – Themes of awareness collection B – Considering the student

Category T1 – Themes of awareness collection C – Secondary biology curriculum

Category T1 – Themes of awareness collection D – Secondary biology teachers

Category T1 – Themes of awareness collection E – Passion for the subject

The name of the category was derived from its predominant constructs (Boulton-Lewis et al., 2001) namely: the instructional authority represented by the curriculum or course syllabus and; decisions about the instructional approach or approaches involved in the delivery of that curriculum.

Each of the five collections of themes of awareness is described in the following section. The representative quotes retain their locater label (e.g. P01:2-10).

Category T1 - Themes of Awareness Collection A – Curriculum Development

From the perspective of curriculum as instructional authority, academic biologists understand curriculum as the blue print of a degree program in biology. They know how that blue print is created and they are accustomed to that blue print being revised periodically, usually in an attempt to improve course selections or in an effort to fit program components with faculty complement, with faculty expertise and with faculty program goals and expectations. Academic biologists are conscious of the manner through which they are able to contribute to curriculum development at a university. The core aspects of a university biology curriculum are decided upon by committees made up of academics who collectively seek to ensure that students in an undergraduate biology degree program are introduced to the basics of the discipline. These committee members are the blue print makers. They are the ones who determine an approach with which to equip university biology students with the essential elements of the discipline (i.e. skills and knowledge). Some academic biologists participate in curriculum committees because they hold an administrative role in which oversight of curriculum development it is part of their job.

P05:2-2 As chair of the department I have to oversee all of the curriculum matters in biology here so it is absolutely critically important that certain subjects are covered; there is no question about that.

Other academic biologists support the work of the curriculum committee by offering input about their particular areas of specialization.

P10:2-2 Right now we are in the middle of a revamping of the second year biology program so I am involved with one portion of that as it relates to the areas that I am interested in and that I teach.

A commonly held conception of academic biologists about the development of a university's biology curriculum is that it is challenging to acquire consensus in the ranks about what biology students need to know and about how that should be packaged. In conjunction with this particular challenge is the indecision about the focus of a biology curriculum. Should it be targeted at students knowing the minutiae of biology or at students knowing the big picture of biology? As such, academic biologists consider whether or not there should be an emphasis on acquiring facts about biology or an emphasis on actually doing biology through application and hands-on experiences.

P03:2-3 There are astonishingly few facts that I regard as essential but the habit of mind is vastly more important. I am really worried that we have kids thinking that biology is a list of vocabulary. Now to be fair, this is almost paraphrasing that rant that I had at [a] curriculum meeting last Friday where everybody is saying that [students] need to know the difference between a moss and a fern, they need to know the difference between a whatever and a whatever, our friend the worm. They need to know about the fins of a fish. Everybody's got their favorite facts.

P07:2-12 Cells are important. Photosynthesis is important. Yes. Everything is important depending upon which specialist you talk to.

P08:2-6 Over the years I have come to believe that there really is not a bible somewhere that says you must cover this material.

A related challenge that academic biologists confess to is the reality that other administrative levels at a university may over-ride a curriculum committee's recommendations.

P01:2-10 So we actually designed that course to be problem based learning and it was meant to replace three other courses which would be one course all problem based, all tutorial, no lectures, those sorts of things. It made it all of the way to faculty council before someone said we can't do that. So in the end it was a compromise. It went back to being a lecture/lab type situation.

Despite the vagaries of a biology curriculum development process at a university, what is taken to be universally understood by academic biologists is that decisions for an individual biology course are made by the professor in charge of it. He or she is the expert in the field, the holder of the content knowledge, the one with the experience to decide what should and shouldn't be part of a course in that specific area of biology. Therefore, academic biologists make various decisions related to individual course planning. In some instances, a biology course structure is systems based.

P01:2-10 In terms of how it was developed, the modules, all the parts of it were really from the idea of "what, so what, now what": get some facts and what do they mean. It is really very basic sorts of things and through systems approach in terms of production systems to get some of that more nitty gritty [subject matter content] into it.

In other instances, a biology course structure is based on the academic biologist's desire to have the students be able to do biology with the knowledge they acquire about biology. While planning the course, the professor is focused on giving biology students the opportunity to apply what they learn to biological systems; to engage with biology; to make connections with the relevance of biology.

P05:2-10 First of all there is a certain amount of knowledge that I want them to have but I don't want that knowledge to be in isolation so I kind of have an expression that I always give to myself when I am planning how I'm going to teach and that is to blur the lines between teaching and research. So I typically do things in units and they are self-contained units that typically involve a couple of lectures and then a component where the student is doing an active hands-on project where they are then taking information that I gave them and using it to carry out this project and then somehow synthesize that combined educational experience, experiential education if you want, into something that I can grade because unfortunately we do need marks. The biggest thing for me is minimal lectures but foundational lectures that give them the information that they need. Not all of the information they need, sometimes the information to find the information they need, but then to put them into a real scenario where they are applying that information in a practical way.

P05:2-12 People learn better by doing and by being engaged and interested in what they are doing. If I can make [a concept] interesting, and I do, then you know it just shows that it can be done with the right sort of approach. People get more engaged when it is hands on and get more engaged when it is real and relevant to their own lives.

A general sense is that course planning is the result of academic biologists filtering through their own subject knowledge, work (research) and interests to set course pillars.

P09:2-10 It was my own design. I just built around integrating my own material and experience.

P03:2-10 I thought about the content I wanted to deliver, what concepts I thought were important and what concepts were interesting for me.

Part and parcel of the course development experience for an academic biologist, especially in recent times, is the need to for the course syllabus to meet institutional requirements. Typically this means that the course syllabus is presented in the form of a universally used template which calls for the presentation of the professor's learning objectives and his or her instructional strategies and assessment schemes. Academic biologists conceive syllabus templates as formulaic. Initial encounters with templates put academic biologists in foreign territory. There are varied levels of commitment to their use.

P05:2-1 There is more and more and more of an emphasis on creating these sorts of structured documents about how we teach and what we teach and what our outcomes are and what our objectives are. However when I had someone on a curriculum committee, I think three years ago, ask me to do a rubric I didn't even know what it was.

P02:2-10 I never formally wrote [my course syllabus] up with a rubric, because I did it just before [my department] started doing that. Now if we are developing any new courses, we have a template.

P04:2-10 I didn't really put a lot of effort in into [the course syllabus]. I've basically used the template and thought about what I expect from the students and made those comments based on what I thought we're doing in the course and what I expected the students to get out of it, determining learning objectives and outcomes. So, it is relatively new doing that and I will honestly admit, I didn't put a great deal of thought into it. But, I see that document as basically just being what I normally do written down in a certain format that's been provided to me. It hasn't changed the way that the course is being offered. It hasn't changed my objectives for the course and what I see as what the students will get as benefits from it. It is just articulated in a different way. I've done those courses for 20 years here so, it's hard to change.

P08:2-11 Well for my courses I have a course outline rather than a syllabus. I have a list of the material that I want to cover although usually there are different components that I use depending upon the interest levels of the class. A lot of this I have never really articulated, for example the curriculum focus or the curriculum links, because I am just holding it in my head and because of the way I structure my lectures. The way I communicate the structure is a really big part to me because I really want them to see where everything fits together. So at the beginning I give them a structure of the course and I go over what we are going to cover in each of those sections and then I keep a running tally so it is like I give them a road map.

There is a conception amongst academic biologists that the course syllabus template is based on aspects of education theory that they are only somewhat familiar with.

P04:2-10 [I used] a template that gets sent from the Dean's office. I know there is some educational background to the setting of outcomes and describing the outcomes and the nature of them. I am sort of aware of those kinds, or at least of that way of thinking about course outcomes and objectives.

There is also the conception that policy about the course syllabus template is aligned with the need for legal accountability to the university.

P04:2-10 Unfortunately most of why there is a template, why we are doing it that way now, is because of the legal aspects.

Academic biologists hold conceptions about teaching assignments that are not theirs by choice but by circumstance.

P02:1-8 I don't think that it was fair to stick the new people in there [first year courses] but when you are new you can't say no because you don't have tenure. Those large classes are the worst thing. And just the realization that I was teaching a bunch of impolite teenagers, I really didn't know that I would get that when I started that job because I really hadn't been around teenagers for a long time.

P03: 1-8 I was assigned with quite short notice to teach genetics, which is not my field, and I was ill and exhausted and overworked and I did a terrible job. They hated me. I hated them. It was a bad experience.

P03: 1-2 I have been crossing over covering course in microbiology and molecular biology, metabolism, introductory biochemistry and genetics a few times. It's a small program so we have to pinch hit.

P04: 1-2 It's a small department so we [teach] many things.

Course planning experiences of academic biologists involve integrating textbooks with the intended course plan. There is acknowledgement that textbooks are useful but that they generally don't entirely fit what is needed. The corresponding awareness is that the academic biologist picks what is useful within the chosen textbook and augments what isn't useful. So the academic biologist doesn't teach the textbook to the student. Instead, the academic biologist teaches aspects of the subject area using the textbook if it applies but using other resources if it doesn't.

P10:2-10 I found a textbook that I thought reflected [the subject] well and then set up the progression from first class to last that I thought reflected or that I thought would best deliver the message that I was intending to deliver to the students. I left out those chapters not necessarily that I found to be irrelevant but that I found less interesting perhaps and felt that it wasn't that critical that they have [that information] but mentioning it in class, obviously. But I just can't cover everything that is in any biology textbook in a term and yet it is interesting, every year I slightly modify it, so remembering what some students liked and didn't, incorporating new material as it develops in the media or from my own experience and putting that in or taking things out.

Academic biologists have the understanding that they don't have to re-invent materials for a new course or for one that they take over from a retiree, or a colleague who has moved to a different teaching assignment. The corresponding conception is that when the professor changes, so does the course. There is collegiality and trust between academic biologists so they share teaching resources and strategies with each other.

P02:2-10 None of my courses have been developed from scratch, but the more recent ones were a little less seat of the pants than the older ones. I have a laboratory [exercise] I use and the nuts and bolts of the doings were extensions of [a colleague's] material that I modified the context of and the whole way I teach it is quite different and I also developed new materials from scratch as well.

P10:2-10 So when I first started developing the syllabus for that course I approached other colleagues who I know that teach it and asked them what they found worked and didn't work and what text books they tended to use, so again, I don't want to reinvent things so I like to go to people who I respect and find out how they've done it and people who I know are good teachers so that gives me the basis.

Additionally, academic biologists, even though they say that hands-on, experiential learning is preferable to lecturing, understand and use a specific language to describe their own teaching. From a pedagogical standpoint, this language has a teacher directed content delivery tone to it rather than a student centered experiential tone. As is the case with teacher centered didactics, when an academic biologist describes his or her plans for the implementation of a course syllabus he or she explains that she will: talk to the students about biology concepts; explain biological concepts to the students; show examples of the biological concept to the students. So when they are being teachers, academic biologists think about transmitting curriculum content to their students.

P01:2-9 I would show them. I would bring up examples that they could relate to. I would bring [the biology concept] to their attention.

P02:2-9 I don't know how much detail I would go into but I would talk about examples to explain it probably rather than to talk about the minutiae.

P03:2-9 I would probably try doing an experiment [to show the students what I mean].

<u>Category T1 - Themes of Awareness Collection B – Considering the student</u>

When academic biologists experience planning for an entirely new course, student involvement plays a role in the decisions that academic biologists make, both from the perspective of graduate students being given an opportunity to contribute as they learn more about what an academic teaching role involves and also from the perspective of what might interest students who will be taking the course.

P11:2-10 A PhD student of mine and I collected up everything we could get on [the subject]. We did searches. We found the books that we could use but when you are trying to develop a brand new curriculum and the only [similar] courses are in California, you have to pick through the information and you almost start with a philosophy. It is a new area and you have to justify that it is an area that is developing and that students would be attracted to it because you are offering something that is unique and then you just look at the unique features that you think fall in within the topic. So a course always has artificial boundaries put on it because knowledge is a continuum and what you do is pick out a slice and tell everybody and tell yourself first what the slice is going to be in this continuum. Then you build on that and you give examples and you get the students involved.

P08:2-11 I tend to make sure that I follow up on some of their interests. I invariably say when I am doing it, one of you mentioned that you really liked such and such so here is a chance for us to talk about this a little more and I find that is one of the things that when they feel that their interests are actually structuring part of what we are covering, at least in the examples, that has an enormous impact on the ones who have suggested it.

The decisions that academic biologists make about the contents and design of a course can be driven by student feedback. The general sense expressed is that a course design can be revised at the suggestion of students.

P06:2-10 First of all, I've taught this course probably seven times. It's one of the first ones I taught when I started teaching at the university level. I've had a lot of chance to revise it based on student feed-back and based on what I learned in the classroom.

P02:2-12 Sometimes the students have those good suggestions about what worked and what didn't, especially what didn't. You should pay attention to those things.

P06:2-10 I have received feedback that there is too much overlap between the lectures and the readings so now I'm doing more stuff in class that amplifies what they've read instead of saying it again.

An additional element of influence on academic biologists' course planning decisions relates to the degree of concern that is placed on student satisfaction, be it with the clarity of a course syllabus, or the professor's explanation of course assignments or the choice of teaching approach for the course.   There is the dominant viewpoint of academic biologists that biology students have distinct expectations about course content. When the expectations aren't met, students are dissatisfied. That dissatisfaction can resonate with the academic biologist.

P04:2-10 Students get up in arms if you're not, if they think they are going to get a course of a certain kind and then it is not like that, and it is not how they interpreted the five lines in the calendar, you know, the description.

P04:1-8 And maybe they don't like [the syllabus] but they don't have to like it. They just need to know that they are actually getting what you think it is that they need to know in order to get some appreciation for the subject matter that you are supposed to be imparting. It's more of a discrepancy between what you are trying to do and what they are perceiving you are doing. There's all kinds of stuff mixed up in that, expectation from both sides about what a student should be doing and what a professor is doing and how that should be done and it can be difficult and frustrating when you can't make that connection.

P09:1-7 They are so used to being in a very strict frame that they are not very prone to take advantage of open, fairly open guidelines. They always ask for the number of pages for this or that and they always ask for a frame.

The academic biologist's response to the expectations of biology students is variously adaptive: focus is on improving student achievement; focus is on what students will agree to acceptance; focus is on perception of fairness and empathy. Academic biologists encompass an awareness of student concerns when they ameliorate their syllabus to encourage student acceptance of the course experience.

P08:2-10 I found that students want to know what are they expected to do and how are they going to be graded. Those are their two biggest concerns. Then over the years I tried to get more specific about assignments that I had them doing because it would say that they had to do a summary of a paper and they wouldn't know what that was so really the first day of class they didn't know what was expected of them so I started writing a description of the assignment and then I realized over the years that wasn't enough for some types of assignments. So I put together a marking rubric and I wrote it in a way that they could understand exactly what I was looking for and I put in, in many cases, the number of marks that would go with each component of that. So if they had to have labelled drawings, they needed to know that the drawings were going to be evaluated and the labels were going to be evaluated. And I found that really gave them a more focused target to hit, for second year in particular. When I taught first year, that is something that they found really welcoming. They knew what they were supposed to be doing and what they were being evaluated on.

P11:2-10 The projects have to be set up so that they know the headings that are going in to that and then they know what the accumulated score is down to the bottom. And I found that students are quite accepting when you divide up the scores so they know how much they are working for that part of the presentation oral, or written.

Experiences that academic biologists have with students' satisfaction about biology course design are positive, negative or a combination of both. A sense of success (i.e. students and professor are satisfied) is commonly associated with small class size, a concentrated timeframe and an experiential component to the course. In other words, academic biologists have a positive conception about courses that are designed to have low student numbers and a teaching environment that allows for students to experience biology either in the field or in the lab. A sense of disappointment (i.e. students and professor are not satisfied) is commonly associated with last minute changes to a course plan. That is to say academic biologists have a negative conception about courses when they feel students underappreciate concessions or accommodations offered by the professor at the students' request.

P05:1-7 All of my best experiences teaching biology have been in field courses. They are extremely intense. When I was teaching in [a field station], sometimes we would be going 16 to 18 hours a day but when you see a light go on or you are living off the enthusiasm of the student and they are living of your enthusiasm and you feel that synergy of learning going on, there is nothing that makes you feel better than that. You can't compare it to anything.

P07:1-7 [The special project course] was the hardest thing these students had done in a long time. It was beyond their scope in terms of being challenging and they couldn't get enough of it and in the end they just had the experience of a lifetime and so we do it every year now. It is not a big group. We get a dozen students and they complain and you can see it on their faces but when you see their manuscripts, they just did their conference posters for us yesterday. These are third year students. They are capable but they have just never had to do anything like this. And here it is and to me that was such a breakthrough. First time in years I felt like I couldn't get to the classroom fast enough.

P10-1:7 So I am fortunate that I am teaching almost exclusively upper year level courses so they tend to be smaller class sizes and so I can afford to take students with me out to the field whether it is day trips or three or four days. This year I have been especially fortunate to be a part of [a course] where I have had a class of 15 students who I have had with me for essentially two weeks and we spent several days in the field. The feedback I get from the students from doing that from them getting to know me, interacting with them, joking with them, walking with them, talking with them, that, to me, is the best part.

P09:1-8 And the type of students who were asking for, they were debating the guidelines for submitting essays, the deadlines and things like that. I remember once I was a little lenient and I said well yeah, we can push it and then some of them were upset at me because some of them had more time than others. I got really upset then because I felt that, well I should have been firm in the first place but I wasn't. I was trying to be nice and then it wasn't nice enough for them or it wasn't suitable to them. There was no solution to their attitude.

Category T1 - Themes of Awareness Collection C – Secondary biology curriculum

Academic biologists' involvement with curriculum development for biology courses in high schools is limited. Their conceptions about a secondary biology curriculum are based on having taken high school biology courses themselves or on the vicarious nature of having children who have studied biology in high school.

P07:2-2 Well [my] 4 children went through it in the NB system in two different high schools.

P03:2-2Well I've had three kids go through high school and I went through high school.

P02:2-2 Zero [involvement in curriculum development], at the school level. At the university level it's not a provincial formula.

P06:2-2 I've worked on courses at all levels at the university level so I've been on curriculum committees. I've done that kind of stuff but I have never worked with anything at the other levels, only the university level.

P09:2-2 Aside from being a student myself, I guess I have no other experience. Of course at the university level, we discuss the curriculum of the undergraduate and the graduate degrees but in terms of high school curricula, I have no experience what so ever.

P04:2-1 I have never seen high school curriculum before. This was the first time.

The understanding that academic biologists have about secondary biology curriculum is that students who take high school biology courses are the student who academic biologists will eventually meet at university.

P04:2-2 I have no experience with high school, of any description, because I don't have kids. My experience has been, really, receiving the products.

Academic biologists conceive the focus of secondary biology curricula to be the result of influence from the area of expertise of the individuals who develop them. Tied to this conception is the perspective that the overall focus of the secondary biology curriculum sways the direction that biology students follow in university. There is a sense that the secondary biology curriculum under-represents the full spectrum of biological science and results in students making decisions about post-secondary science education that are not fully informed.

P02:2-4. And it's no wonder so many of them want to go to medical school. It looks like they are being tracked for medical school in grade 12. I couldn't believe that there were ten hours spent on neurons. There must be somebody on the curriculum who is into neurobiology. The nervous system and the endocrine system alone is twenty hours and then ten hours for evolution!

There is a conception held by academic biologists that the high school biology curriculum is content heavy and that it is somewhat redundant since biology students will cover that same material in their first or second year university courses.

P04: 1-1 From what I could gather, the information, the depth of the information was really very much what the students get when they come into first year biology in university.

P05: 1-1 It certainly seemed like a first year university course in terms of, I think our university first year biology courses cover a lot of the same stuff.

P06: 1-1 . I thought it was a lot of material for one course. It certainly seemed like a first year university course in terms of, I think our university first year biology courses cover a lot of the same stuff.

Academic biologists find that even when students say they remember learning a biology concept in high school, that learning doesn't allow the students to work with the information when they meet it again for the first time at the university level. In that light, biology courses at university involve having students relearn biology from their courses in high school.

P08:2-4 A lot of this is the stuff we cover in first year and some of it explicitly in second year and I guess the thing I note about it is that when we have students come in from a biology program at a high school and they are taking our first or second year biology classes where I see them first, I think it is really interesting that I can say OK we are going to cover something on photosynthesis and they'll say oh we know all about photosynthesis and then we'll do something about it and they actually don't even remember the basics, they remember the word but they have no recollection of how it works.

P06: 2-11 They will have lots of chances to relearn this stuff.

A related understanding of academic biologists is that the excessive content in the secondary biology curriculum is restrictive in terms of it taking a lot of time to cover. There is a perception that the learning environment cannot be investigative or hands on when there is a focus on the amount of content to be studied. Experiential learning is engaging but it requires time and it requires resources. Problem solving skills are more important than memorizing content.

P01:2-1 I thought that [the secondary biology curriculum] was difficult to get a lot of experimental hands on in some cases and was wondering, as I went through it, how I would keep the students engaged.

P10-2-1 Where was the time and opportunity for hands on experiential learning which is what I am really big on and opportunities for field trips?

P06-2:4 It wasn't clear to me how much, because it's sort of a suggestive document, so it says students could do this, depending on what resources are available.

P03:2-9 I would be doing what I could to try to emphasize experiments or field observations.

P03:2-1 I am far more interested in trying to inculcate a quantitative habit of mind, a skeptical observant habit of mind that looks at evidence on an issue and seeks out the necessary facts to decide on that issue and then attempt to come to some sort of reasoned decision.

Also, with respect to the development of the secondary biology curriculum, there is a dominant viewpoint amongst academic biologists that the secondary biology experience needs to result in students having a level of understanding with which to make informed life decisions, especially if the student chooses to end his or her study of biology when he or she graduates high school. There is the related perception of a need for the secondary biology curriculum to put a strong focus on STSE (science, technology, society and environment) connections.

P07:2-3 I tell my students here that if you know how life works at all then you have a pretty good shot at understanding anything you are looking at because I don't care what you are, it is n, to 2n, to n or it is n,n,n,n; all the life cycles in the world. To make people memorize 150 life cycles instead of one and then worry about the variations. Seems to me they have missed the idea, the concept of how things live. It will take you a long way but trying to pack too much stuff and trendy stuff in just dilutes your ability to fundamentally know what is happening.

P05:2-5 One of the things [is] the importance of educating [at high school] is because most of the kids aren't going to go on in biology so "responsible citizenship having a foundational understanding of the importance of biology to their everyday lives, environmental issue, health issues". I see that is relegated [in the curriculum document] to five hours if I have read that correctly which I find absolutely stunning. Most of these kids are not going on to be biologists so what do we want them to learn anyway would be my question.

P06:2-12 Who knows where these students are going to go . Its giving them those things that they might remember in ten years even if they become a real-estate agent or whatever. That's what I feel is almost more important than training a specialist that actually has a biology career. It's the ones that this may be the last biology course they ever take. Those are the ones we can really show them how relevant this stuff really is.

P06:2-3 I think that the STSE was also good for students who may not go on in biology. They need to see where that knowledge fits in to a bigger picture.

Category T1- Themes of Awareness Collection D – Secondary biology teachers

Academic biologists realize that high school biology teachers acquire expertise in pedagogy during their teacher preparation programs. This expertise allows the teacher to understand the varied components of a secondary biology curriculum document including what is meant by specific teaching strategies found within it. It is acknowledged that there is seldom a comparable focus in university post-graduate degree programs that prepare individuals to be academic biologists.

P07:2-1 When I read [the teaching suggestions], I would not know how to teach biology and I would probably violate several of the concepts there, trying to move forward.

P11:2-7 There is such a philosophy of teaching which I don't know anything about. I can't even talk the talk let alone walk the walk.

Category T1 - Themes of Awareness Collection E – Passion for the subject

Academic biologists make instructional decisions based on their passion for the subject area.

P08: 1-7 The part I really enjoy, unfortunately, is probably the part where I am telling them something that I think is really exciting and then seeing them get excited too and that is a really bad thing because I have a hard time pulling back and letting them do the teaching and letting them do the learning. I want to be in there. I want to be part of that exciting stuff and I really have trouble just shutting up. I really do and all of these different teaching techniques where you let them do the learning and where you step back, I'm not good at that but on the other hand that tends to be, I can use that as a strength because I have learned over the years that my own excitement and enthusiasm for whatever reason is one of the things that does catch them so if they are not already hooked on the topic that really does get them excited so I rationalize it that way.

<u>Referential and Structural Aspects of Category CT1</u>

The referential aspects of Category CT1 were determined to include the following as illustrated by the accompanying quotes (which are presented in italics):

- providing input to curriculum

Right now we are in the middles of a revamping of the second year biology program so I am involved with one portion of that. P10:2-2

- developing course syllabus

In terms of how it was developed, the modules, all the parts of it were really from the idea of what, so what, now what. P01:2-10
So when I first started developing the syllabus for that course I approached other colleagues who I know that teach it and asked them what they found worked and didn't work…so I like to go to people who I respect and find out how they've done it and people who I know are good teachers so that gives me the basis. P10:2-10

- considering the student experience

I tend to make sure I follow up on some of their interests. P08:2-11
The projects have to be set up so that they know the headings that are going in to that and then they know what the accumulated score is down to the bottom. And I found that students are quite accepting when you divide up the scores so they know how much they are working for that part of the presentation, oral or written. P11:2-10

- considering the professor experience

All of my best experiences teaching biology have been in field courses. P05:1-7
I am fortunate that I am teaching almost exclusively upper year level courses so they tend to be smaller class sizes and so I can afford to take students with me out to the field. 10:1-7

- understanding suggested teaching strategies in the secondary biology curriculum

I would not know how to teach biology and I would probably violate several of the concepts there, trying to move forward. P07:2-1

The structural aspects of Category CT1 were determined to include:

- curriculum oversight

As chair of the department I have to oversee all of the curriculum matters in biology here. P05:2-2

- course autonomy

It was my own design. I just built around integrating my own material and experience. P09:2-10

- course content

I thought about the content I wanted to deliver, what concepts I thought were important and what concepts were interesting for me. P03:2-10

- experience with secondary biology curriculum

I have never seen high school curriculum before. This was the first time. P04:2-2
Zero at the school level. At the university level it's not a provincial formula. P02:2-2

- content of secondary biology curriculum

I thought it was a lot of material for one course. It certainly seems like a first year university course in terms of, I think our university first year biology courses cover a lot of the same stuff. P04:2-2

- time and resources for doing biology/engaging with biology

I thought that the [secondary biology curriculum] was difficult to get a lot of experimental hands on in some cases and was wondering, as I went through it, how I would keep the students engaged. P01:2-1

- need for general biology literacy

One of the things [is] the importance of educating [in] biology for a responsible citizenship having a foundational understanding of the importance of biology to their everyday lives, environmental issues, health issues. P05:2-5.

Category T2 – Biology teaching varies between the secondary and tertiary levels of the education system

Four different collections of themes of awareness informed the description of this study's second category pertinent to biology teaching (Category T2). Based on their primary focus, these themes are:

Category T2 - Themes of awareness collection A – Curriculum continuum critique

Category T2 – Themes of awareness collection B – Teachers and teaching at the high school level

Category T2 – Themes of awareness collection C – Collaboration

Category T2 – Themes of awareness collection D – Excellence in biology teaching

The name of the category was derived from the predominant constructs: the sense that academic biologists have of the continuum of biology education through high school and university; the conception that high school biology teachers experience the secondary biology curriculum differently from the way academic biologists experience the tertiary biology curriculum; the understanding that academic biologists have of constraints that biology high school teachers face in their work.

Each of the four collections of themes of awareness is described in the following section.

<u>Category T2 – Themes of Awareness Collection A – Curriculum continuum critique</u>

Academic biologists conceive the biology curricula that are implemented in high schools as being precursors to the curriculum that they themselves teach at university.

This conception is multi-faceted. For example, there is a positive critique of the dimensions of the secondary curriculum.

P01:2-1 It takes a very classical approach to biology.

P06:2-1 I was impressed at how in depth it seemed to get.

P08:2-1 Obviously it is not exhaustive but I like the choice of topics as ones that are meaningful in the field and also have the potential for capturing the interest of people who may not know a lot about biology so showing them areas where, in fact, biology does connect to their lives.

P04:2-4 I think the high school preparation as it is described there is good. It will give the students a taste of what they are going to get in university but they will also get exposed to a more intense requirement for gathering information and for thinking about stuff. So, I think that's how [the secondary and tertiary curricula] mesh and how the two systems work together.

P04:2-2 It seems that the high school curriculum is well integrated with what students will get exposed to when they get into biology in university. I think that is a good thing.

P08:2-1 What I see is appealing to a broad range of learning styles and different sensory things so there is in the lab, there is in the field, there is talking about it in terms of the people who did this, there is talking about it in more esoteric terms, there is a balance of skills and knowledge and those, for the most part, are separated which is nice because most of the time we [academic biologists] tend to conflate them and get things a little bit jumbled. And even seeing things like there is experimental design, just beginning to start on those things and the structure of a scientific paper or in this case a scientific report. Those are all things I would really hope to see in a curriculum.

There is also a negative conception held by academic biologists of scope of the secondary biology curriculum.

P02:2-1 The focus is mainly on human biology and is very restricted to animal biology and the perspective on so called diversity is not very diverse.

P07: 2-1 I understand the importance of context but I don't understand why that becomes the thing that they are learning about rather than moving forward with some relevant biological knowledge. It is odd that they emphasize certain topics over others.

P07:2-1 They end up with human physiology which is biology. I presume they are using it as a model for other living things and they want to make it relevant to young people. But I have got to say that from a biological, ecological impact point of view there are lots of other ways to fundamentally understand circulatory systems and immune responses through any number of mechanisms.

Gaps and authenticity in content and learning for students are likewise perceived by academic biologists as problematic in the high school biology curriculum.

P01:2-1 Since my background is plants, I thought it was a little light on the plants, a little heavy on humans. I mean it is easier to teach in high school about humans because they have the organism with them all the time.

P02:2-1 It kind of fits with what we see in first year university. When they come in they don't really know a lot of stuff about microbial biology or plant biology. I don't see anything in the curriculum to deal with quantitative data and statistics even though there is mention of that in the skills and then in the appendix. And in the lab report outline it talks about things being statistically analyzed but there nothing in the curriculum.

P07: 2-2 Things they call experiments are just observational. It makes me crazy. Turn your seed upside down and it still grows up. Geotropism. Fantastic. Not an experiment unless you have framed it in a way that there is an alternative that could possibly happen so that then you could measure it with statistics. And then students really know whether they have significantly seen something odd or something real.

When biology concepts that are taught in the high school curriculum are repeated in university, academic biologists hear complaints from students. These complaints are unwarranted in the minds of academic biologists who feel that students don't really learn biology before they come to university, even if they took secondary level biology courses. The overlap between the secondary and tertiary biology curriculum would seem to mean that there is no need for repetition and that there is potential for academic biologists to do something different in first year biology courses. The understood reality is that tertiary biology starts from the basics in the first year of study and moves to a more detailed focus in upper years.

P06:2-4 So certainly there is a lot of overlap and you know, students do comment on that, because I remember this, I saw all that stuff in high school and then you would see it again in first year university so it's kind of like we've already done this but, the university level is much more in depth and there is a higher expectation. It's harder. [Students] have got to really know this stuff.

P08:2-4 I can say OK we are going to cover something on photosynthesis and they'll say oh we know all about photosynthesis and then we'll do something about it and they actually don't even remember the basics. They remember the word but they have no recollection of how it works. And I guess there are two parts there. One is, yes they covered it[in high school] but do they remember anything or do they have any deeper understanding of it? Can I build on that? No. Usually not. There are a few who have a sense but they've got it memorized as an equation often and that is it. That's not to say it was taught that way but that's what they come in with. Then the other thing will be that they think if they've covered it that they know it already and they are quite resentful that they are going to be spending a whole year learning what they already know. My explanation to them has usually been something like I know you have covered the basics of it. We are going to cover it more deeply and we also want to bring everyone who has had different coverage of the material up to the same level and they will go along with it but the first job is overcoming that sense that we already know this and then, if I am talking about a particular topic and they've said they've covered it and I say well Ok that you remember that all cells have this outer shell on them that is different in animals than in plants what is that again and of course they don't have a clue so clearly the are not remembering or internalizing and that is not unexpected because we know that learning anything repetition reinforces things.

P04:2-1 These kids should have gotten all that in high school and but then we go through that process and we give it to them again. Maybe it's good to repeat this. I was quite struck by that. If I looked at that [high school] curriculum and I knew that the students coming into the university system had that stuff down, I would be looking at doing something completely different than what we do now in university.

P04:2-4 Students that are going into an introductory level biology in our first year biology course [cover] the entire spectrum from molecules to ecosystems in one year. There is a great deal of effort put into trying to touch on, and it really is still that level of touching on without a great deal of depth but certainly touching on the whole spectrum and with the assumption that as they progress through to a degree, that they are going to develop their own interests in specific areas and they are going to get into more detail as they progress through the upper levels.

There is a concern amongst academic biologists about the secondary biology curriculum's focus on memorizing and regurgitating course material. There is less emphasis on ensuring that students understand and can apply their knowledge. Describe.

Define. Explain. These are the most elemental aspects of what doing biology is all about and they require limited thinking, on the part of the student, about a biological concept.

P03:2-4. And if it is going to be one of these biology vocabulary courses where you memorize words, get facts and give multiple choice answers it could be that this curriculum will fare them pretty well.

P03:2-1 I just can't see that on page 16, Spallanzani is something that every high school student should know and yet I read Spallanzani once and I read evolution twice so does that say that Spallazani is half as important as evolution? So I am concerned about the risk of sliding in to lists of facts.

P07:2-11 I am not very interested in memorizing anymore. I am very interested in understanding and I get my students to create flow charts of what they learn and what comes from what. But I am really horrified by some of the suggested assessments which would so easily fall into just memorizing.

P11:2-4 What I really think is important is the ability of the teacher to stimulate the students to really understand what is here instead of memorizing; to actually work with their hands and bring all of their senses to the information.

<u>Category T2 – Themes of Awareness Collection B – Teachers and teaching at the high school level</u>

There is a conception held by academic biologists that the way a high school biology teacher presents the secondary biology curriculum to high schools students is a factor of influence in the student experience.

P04:2-4 I really think that it will boil down to the slant that the teacher puts on it.

P11:2-4 What I really think is important is the ability of the teacher to stimulate the students to really understand what is here. Instead of memorizing, [students should] actually work with their hands and bring all of their senses to the information. It is sight and sound. That is the way teaching is in the classroom. Sight and sound. There is no smell. There is no touch. The other senses are not involved in teaching. So if you can get the students to use all of their senses then they will be able to remember this stuff, and be able to build on it.

Academic biologists believe that high school biology teachers are not able to move beyond the curriculum when it comes to course delivery and the use of outside experts.

P08:2-12 Their curriculum doesn't allow them time to do anything that isn't in the curriculum and that is sad. Because of the way I can follow my students' interests in a given class, we can cover slightly different material but still get those concepts across. I feel that when a teacher has an opportunity to develop something more hands on and can bring in someone to do something different, the fact that the curriculum prevents them from doing that, I think that is really, really sad.

It is believed by academic biologists that teachers make choices based on whether or not they are comfortable with a specific biology concept. What is important to academic biologists with respect to generating student enthusiasm and engagement with biology is the teachers' background expertise in the subject area. Academic biologists believe that biology is a diverse subject and that, by definition, this makes it difficult for a single person to have expertise in all areas of the science. Academic biologists are unconvinced that a high school biology teacher would be sufficiently qualified in all areas to biology to teach it well. They perceive that if a biology teacher is uncomfortable with a curriculum area, it will be one that they drop from the biology course.

P08:2-6 If you have somebody skilled in an area, they can really do a good job on that. I've had so many students telling me about how they hated the bit they learned about plants and that their teacher told them "I am not very good at this, I don't know about plants". And I have had high school teachers tell me that. They are not comfortable with plants so they just avoid covering it.

P01:2-3 To a large extent there would be quite a number of teachers who wouldn't have the background knowledge to be able to draw on a simple starch test in some cases or whatever. I don't know whether all of the teachers now who teach biology all have a good biology background or not. If they have a good solid biology background they might be able to do it. What I worry about is a chemistry major or a physics major ending up teaching biology and not having the ability to do this. I mean that's a poor assumption I suppose but it certainly happens.

P05:1-6 So I think that when you have one person trying to do all of these sorts of things, whether or not the students are actually getting a comprehension of the individual discipline I guess would be the only thing I would bring up to that.

Add to the understanding held by academic biologists that the high school biology curriculum might be taught by a teacher with a limited background in biology is the perception that the curriculum document provides insufficient support for those inexperienced teachers. There is a question held by academic biologists about the provision of resource materials for teacher to use in their classrooms, especially teachers who give consideration to the opportunities in the curriculum for implementing creative teaching strategies.

P09:2-5 I don't know if the teachers get the support because what I see here is only a four line paragraph [in the curriculum document], with no details. So, if teachers are left to themselves, knowing that oftentimes biology teachers have very little biology background, sometimes they are chemists or physicists, so in those four lines, if I wasn't involved in environmental issues, I wouldn't know where to start. And I think students in high school [think] the problems with biodiversity stem from pollution and that's about it. They don't know the concept about habitat or they don't know the drivers of habitat loss, fragmentation, degradation. So, unless the teacher has real life experience, I'm not sure that part, which is so critical, is well taught. So, maybe it's not the matter of things missing from the curriculum but it's maybe about the tools that are given to the teachers to actually implement them.

P01:2-3 There are opportunities in this curriculum for teachers to be fairly creative however I would worry about them being constrained both by their own experience and by materials in the high school.

P08:1-11 I have to say that almost all of the high school teachers I've met who are teaching biology have a really weak or non- existent biology background or science background.

P09:2-11 I think the key problem is the fact that if you don't have biology training, then it must be much harder to do a good job.

P09:2-11 I don't know who had the crazy idea of allowing people to teach whatever is needed instead of getting them to teach in their specialty.

P08:1-11 I am not criticizing the people who are teaching biology and don't have the background because they have been put in that situation and all the ones I have talked to say that they wish to goodness that they did have more background. They wish that they could do those things. It seems to me we are not getting a lot of people coming in with a good biology background and the people we have teaching well often they are phys-ed teachers who have a really human oriented perspective on things in the curriculum. I just don't think it is doing a service.

A dominant viewpoint of academic biologists is that teachers of secondary school biology are not biologists, even if they have an undergraduate biology degree. This introduces another layer of skepticism about teacher effectiveness. It also introduces questions about whether a BSc. in biology provides a student with an understanding of what doing biology is all about that he or she can tag on to his or her teacher preparation program and, thereafter, in to teaching biology at the high school level.

P07:2-2 I do respect that if you have a BSc in Biology you should have some basic concepts in biology and then you go and do your education degree. That's not a bad thing but you are not a biologist. I don't think you have to be a biologist but I think you have to personally be engaged in what you are doing to the extent to be able to understand how the guidelines that you have been provided can come alive for your class. That is where I saw a disconnect. So they knew the concepts because they took university biology courses but if you challenge them a little bit on some of these things well, that is not really what they did [when they were biology undergraduates], is it?

There is a viewpoint of academic biologists regarding expectation of high school teachers to focus on marks and on testing and evaluation. Measuring student achievement is a component of biology education, both the secondary and tertiary level of education but the degree to which student assessment impacts decisions about instruction is burdensome for high school teachers, in the minds of academic biologists. Academic biologists are themselves not fans of having the responsibility of assessing their students learning and course performance.

P07:2-12 Well I think my disappointment with high school curriculum is [teachers] are trapped into doing what is necessary because there is going to be testing at the end of the day, and that leads to preparing for the test which is very easy to do.

P06:1-8 I guess grading in general, a lot of people are frustrated with it. But it's also frustrating when you get issues that aren't part of your course. For example basic literacy, numeracy and those kinds of things which I don't feel responsible for to the students that were supposed to come in with, and they don't. It's frustrating. Grading is always the worst, having to evaluate students and having to actually [rate] good, bad. I hate that part.

P11:1-8 I did not particularly enjoy marking exams. I would rather leave that stuff out but the system required that you did things to make it work. That's what I really least enjoyed because nobody is learning when you do that and I try to make that still a learning experience by at least providing lots of feed back to the students. To me it was sitting down and drinking too much coffee and trying to plow through all these answers and all the essays, short answers.

The professional development options for biology teachers are generally conceived by academic biologists to have the potential to impact the high school biology program but there are questions about what the focus of those options should be.

P03:2-4 What are they doing in their professional development days? Are they getting ideas and notions and lesson plans and course planning to engage quantitative analysis and decision making and evidence based decision making?

Category T2 – Themes of Awareness Collection C – Collaboration

Their experiences of interactions with schools and teachers have caused academic biologists to form a perspective about collaborations within levels of the school system. There is openness to such collaborations and a perception of the need for them to be respectful of collaborator expertise. That said, academic biologists are aware that high school teachers are dis-inclined to approach university professors about matters related to biology teaching, for a variety of reasons.

P08: 2-12 I would like high school teachers to be able to make use of faculty members in various topics to get excited, to come up with ideas, to come into their classes, to do whatever would be good and not in a remedial way or in a critical way or somehow thinking they are not doing a good enough job on their own because they have far more to do that we do especially in teaching load. I guess that one thing I would wish for in an ideal world is for a closer connection for faculty members at the university to work with teachers.

P09:2-8 I think teachers could also try to contact university professors if they are close to the universities because a lot of us would be willing to spend some time in their classroom.

P08:2-11 So when I've talked to high school teacher, there are two things that they say to me. "I was really intimidated and I didn't think anyone would want to help me" and "I didn't know much".

<u>Category T2 – Themes of Awareness Collection D – Excellence in biology teaching</u>

Academic biologists integrate aspects of their professional experiences to develop a perspective of what represents biology teaching excellence at both the secondary and tertiary level.

P08:1-10 Something that makes them stop and think which probably is saying starting to see signs of critical thinking that are associated with what they've learned. Excellence would be not just having them learn a bunch of things that they number one are likely to forget and number two do not see the relevance of.

P10:1-9 Nurturing that curiosity and me helping them really understand things so they can problem solve, or approach the problem and solve it themselves.

P06:1-9 It's when they get fired up, when they get excited. Any teaching which leads to that, that's where it is at.

P05:1-9 If you can have people integrate the knowledge they are given with the day to day tasks that they are doing into something that is fundamentally better than either of those two things then that is probably the most important aspect of learning in biology. It is taking book knowledge and experiential or lab knowledge and understanding how the two merge and mesh together and then being able to take the next step and apply that to another situation so it is not just lab A and lecture B, but saying "Oh, I get it!"

P01:1-9 Enthusiasm, in stimulation, drawing the students out, challenging them but all of that means you have to be well prepared, organized, good communicator, all of those things in order to do that but when the students are challenged then I think that's when its excellent.

<u>Referential and Structural Aspects of Category CT2</u>

The referential aspects of Category CT2 were determined to include:

- addressing gaps

Since my background is plants, I thought it was a little light on the plants, a little heavy on humans. P01:2-1
The things they call experiments are just observational. P07:2-2

- emphasizing knowing biology

I am very interested in understanding and I get my students to create flow charts of what they learn and what comes from what. P07:2-11

- emphasizing doing biology

Instead of memorizing, actually work with their hands and bring all of their sense to the information. So if you can get the students to use all of their sense then they will be able to remember this stuff and be able to build on it. P11:2-1

- acknowledging skill deficits

[The teachers] are not comfortable with plants so they just avoid covering them. P08:2-6

- coping with testing and evaluating

Well I think my disappointment with high school curriculum is [teachers] are trapped in to doing what is necessary because there is going to be testing at the end of the day and that leads to preparing for the test. P07:2-12

- addressing curricula overlap

These kids should have gotten all that in high school but then we go through that process and we give it to them again. Maybe it is good to repeat this. I was quite struck by that. If I looked at that curriculum and I knew that the students coming into the university system had that stuff down, I would be looking at doing something completely different than what we do now in university. P04:201.

- defining teaching excellence

If you can have people integrate the knowledge they are given with the day to day tasks that they are doing into something that is fundamentally better than either of these two things then that is probably the most important aspect of learning in biology. P05:1-9

The structural aspects of Category CT2 were determined to include:

- qualities of secondary biology curriculum

It takes a classical approach to biology. P01:2-1
I think the high school preparation as it is described is good. P04:2-4
The focus is mainly on human biology and is very restricted to animal biology and the perspective on so called diversity is not very diverse. P02:2-1.

- teacher background

I don't know whether all of the teachers now who teach biology all have a good biology background. P01:203.
I am not criticizing the people who are teaching biology and don't have the background because they have been put in that situation and all the ones I have talked to say that they wish to goodness that they did have more background. P08:1-11.
I don't know who had the crazy idea of allowing people to teach whatever is needed instead of getting them to teach in their specialty. P09:2-11.

- instructional resources to support teaching

There are opportunities in this curriculum for teachers to be fairly creative however I would worry about them being constrained both by their own experience and by materials in the high school. P01:2-3

- potential for collaborations

I would like high school teachers to be able to make use of faculty members in various topics to get excited to come up with ideas, to come into their classes to do whatever would be good and not in a remedial way or in a critical way or somehow thinking they are not doing a good enough job on their own because they have far more to do that we do especially in teaching load. P08:2-12.

- assessment

I did not particularly enjoy marking. I would rather leave that stuff out but the system required that you did things to make it work. That's what I really least enjoyed because nobody is learning when you do that. P11:1-8.

Category T3 - Biology teaching is an extension of academic biologists' own experiences with biology as a study subject, as a science discipline and as a career.

Two different collections of themes of awareness informed the description of this study's third category pertinent to biology teaching (Category T3). Based on their primary focus, these themes are:

Category T3 – Themes of awareness collection A – Levels of engagement

Category T3 – Themes of awareness collection B – The influence of experience

The name of the category was derived from the predominant constructs: the influence of personal experience on academic biologists' perception of being a biologist; what makes them choose their teaching strategies; how academic biologists describe their own teaching through time; academic biologists' experiences with teaching biology are different as they progress through their careers.

Each of the two collections of themes of awareness is described in the following section.

Category T3 – Themes of Awareness Collection A – Levels of engagement

Academic biologists are able to define what brought about their initial involvement in the science of biology. They conceive their upbringing and lifestyles as contributing to their interest in biology as a science that they wanted to pursue as a career.

P03:1-1 I was already quite engaged in biology even before high school because my father had a farming background and was always very interested in farming and agriculture and forestry so I was quite biologically aware.

P04:1-1 I grew up in [a province in Canada] and we spent a lot of time outside, looking at things and going to the beach and that sort of stuff so I was interested in what I saw around me that was biological in nature.

P06:1-1 It related to my background, you know, canoeing and camping and stuff like that.

P11:1-1 I grew up in [a province in Canada] on a farm and of course was always interested in everything from hunting and fishing and so on.

Academic biologists also conceive their early exposure to biological concepts and processes in school as a basis for what followed in their education and work.

P01:1-4 The biology curriculum [during the participant's time in high school] was very much ecologically based. It was investigative, going into ponds, that sort of thing. Capturing, getting water samples. Getting soils samples. There was a lot of aquatic biology. I certainly enjoyed the aquatic part of it. In fact, I took an advanced limnology course in university probably as a result of that.

P10:1-4 I remember having hands on type work with animals which I've always loved so that, to me, is by far the best and what I enjoy the most and I still follow that to this day with my own classes.

P08:1-5 Getting names for things and finding out how they worked and having these interesting factoids, that was absolutely the best early on. I still really enjoy that but later on discovering how you could actually set up something to answer a question that if you didn't know something and you couldn't find it in the books because we didn't have Google, that you could design an experiment to find out and sort of that whole idea of methodical thinking.

There is an influence on academic biologists' teaching that is residual from the actions and attitudes of their own professors: academic biologists pattern from these influences in their own teaching or they avoid perpetuating them.

P05:1-5 In my undergrad, I took my first [specific subject] course. Just the way it was taught. I never thought I was going to be [that type of biologist] but the prof was very experiential. We showed up. It was an all-day Tuesday class. We'd show up with our gear. We'd collect things. We'd bring them back to the lab and we'd work on them. We would study them ourselves. We might have had three or four lectures in the entire course. Most of it was self-discovery and interaction one on one with the professor, and doing.

P05:1-11 In the first few years [at university] you just take what is given to you but as you start to get really, really good courses and engaged professors, you tend to become a little more demanding or expecting of how you want to be taught. Maybe around that time I knew that I wanted to go on to be a professor. So maybe that tainted my perceptions; my opinion about how a professor would run a course, what is good professing and bad professing. All of my best experiences teaching and learning have been hands on. They have been discussion. Even if it has not been hands on in the field doing this or doing that or hands on in the lab doing this or doing that they are discussion hands on where there is interaction and exchange of ideas where the prof has been obviously enthused about what he is doing and engaged in things.

P06: 1-11 My PhD supervisor was an awesome teacher, really inspiring and I learned a lot from him about teaching. And I took a course on how to teach at the university level. All of these things came together. So those were really important formative things for me in terms of how teaching can be part of my biology career.

P08:1-1 I really learned how a PhD program shouldn't be and how not to be a supervisor [because] my supervisor did a fair bit of teaching and was a horrible teacher.

<u>Category T3 – Themes of Awareness Collection B – The Influence of Experience</u>

Academic biologists share the perspective that time is required to reach a level of teaching competence and a sense of self-satisfaction with one's teaching abilities. There is a recognition that approaches and styles of teaching vary with time and with experience. Personal experience is a factor of influence on academic biologists' thinking about teaching. In essence, learning influences an academic biologist's conception of teaching. Learning to teach by being taught influences an academic biologist's conception of teaching. Learning to teach by teaching others influences an academic biologist's conception of teaching.

P09:1-7 Well actually it took me a while to really succeed with students.

P10:1-9 I have never yet attained it first of all to a point I'd like because I think it is a continuum. You are always improving. I don't believe that you ever have your course set so that you never have to research it or prepare it again. No I am always updating. I need to make the stuff interesting for me so that it is interesting for them.

P08:2-10 Through the years, each year was a response to what happened in the previous year so it was illustrating my growth as a facilitator of learning.

P02:1-11 There must be as many styles as there are biology teachers. And everybody's experience informs how they teach.

<u>Referential and Structural Aspects of Category CT3</u>

The referential aspects of Category CT3 were determined to include:

- perfecting approach over time

Each year was a response to what happened in the previous year so it was illustrating my growth as a facilitator of learning. P08:2-10
Well actually it took me a while to really succeed with students. P09:1-7

- teaching from example

I really learned how a PhD program shouldn't be and how not to be a supervisor [because] my supervisor did a fair bit of teaching and was a horrible teacher. P08:1-1

The structural aspects of Category CT3 were determined to include:

- influence of life experiences

I was already quite engaged in biology, even before high school because my father had a farming background and was always very interested in farming and agriculture and forestry so I was quite biologically aware. P03: 1-1

- influence of school experiences

[High school] was very much ecologically based. It was investigative, going into ponds, that sort of thing. Capturing, getting water samples. Getting soils samples. There was a lot of aquatic biology. I certainly enjoyed the aquatic part of it. In fact, I took an advanced limnology course in university probably as a result of that. P01:1-4.
In my undergrad, I took my first course. Just the way it was taught. The prof was very experiential. We might have had three or four lectures in the entire course. Most of it was self-discovery and interaction one on one with the professor and doing. P05:1-5.

Categories of description about biology learning (CL1, CL2, CL3)

<u>Category L1 - Biology learning results from doing biology through preferred process and place</u>

Two different collections of themes of awareness informed the description of this study's first category pertinent to biology learning (Category L1). Based on their primary focus, these themes are:

Category L1 – Themes of awareness collection A – Learning by doing

Category L1 – Themes of awareness collection B – Learning essential elements

The name of this category was derived from the predominant constructs: the experience that academic biologists have with learning biology through doing research, collecting data, making observations, collaborating with colleagues; the accumulation of learning experiences (preferred or not) through different levels of the education system.

Each of the two collections of themes of awareness is described in the following section.

<u>Category L1 – Themes of Awareness Collection A – Learning by doing</u>

Doing biology to learn biology, as a biology student, is perceived by academic biologists as undertaking independent research through projects.

P06:1-5 It's the independent stuff. When I had my own data [during an honours project], I had that sort of ownership over it. It was my project and of course, things don't go according to plan but it was at the very end when I started to see, I got it, what research was about because, you know, I finally had conclusions that I had carried through to the end and it was when I could finally see, a whole bunch of other questions opening up. Oh! This is what I would do next. Oh! That would be cool. Oh! I could do a masters [degree] on this. This would be a great question. That is when I got it.

Doing biology to learn biology, as a biology student, is also perceived by academic biologists as a given part of their course work, be it in a preferred fashion or not.

P05:1-4 The best experiences I've had were in advanced courses where we could specialize and discuss the subject matter, be allowed to have various interpretations sometimes of the subject matter instead of cramming our brain with things that we have to learn by heart.

P06: 1-5 It's the hands on,stuff. I am a very independent learner. I teach myself stuff. I didn't find classroom learning to be something that I enjoyed. And so, it was that independent research that really stuck with me and it was also the field work, being out there. Just observing stuff, seeing stuff and getting interested in things.

P07:1-1 I learned fundamentals of biology in a number of different course. The best part of studying biology in university to me was always the labs. I learn by doing probably more than by listening.

Academic biologists are able to offer examples of the process they would choose to follow if they identified gaps in their knowledge about biology that would impact their ability to do biology. Even as experts in their field, they have preferred ways to learn biology.

P02:1-6 [I would choose to] spend some time in another lab, embed myself in another lab and work there on a project that required me to learn it. Then there is no procrastination and motivation problem because you have to catch up with the other people and that's probably the best motivator instead of constructing some artificial problem or something you want to do just to learn the stuff. You are actually working on a project.

P04:1-6 I would probably try and find somebody who knows a lot about it and I would go to them and see if I could coerce them into teaching me.

P05:1-6 First I would do some reading, second I would be bouncing emails off of people that I know that know the subject area. I would attempt to get to workshops or conferences on the topic. In a sabbatical year, I would try to visit a lab where I would get hands on, firsthand experience with things that I am interested in. You can do a short visit into someone's lab and get a little bit of first hand experiences. That's the best way to learn.

P10:1-6 I am a big fan of mentoring. I want to have experience with something but I want someone there who can mentor me along the way. And then it's hands on. It's trial and error. I like learning by doing. I would like someone first to give me a basic lesson on understanding, a rather simple exercise, allow me to make mistakes but to experiment and hopefully progress with each step and then get feedback along the way with progressively more difficult steps.

P11:1-6 I have to link base with people who know more than me. I have always known this, that there are a lot of people who know a lot more that I do. So that's kind of how I'm going to learn and I will do it all the way from the web work to meeting people.

Category L1 – Themes of Awareness Collection B – Learning essential elements

With respect to the learning process of academic biologists, a conception of disenchantment is tied to their recollections of some of the required elements of learning their profession. In other words, academic biologists are able to describe the aspects of their biology education that were not what they expected or that were not their preferred way of learning. The corresponding consciousness is that they managed to navigate through these bumps on their education path such that the disenchantment is understood to be a part of the learning process.

P06:1-5 The actual implementation of [the course] fell short of my expectations. We didn't seem to know any of the theory going into it. We didn't know what we were doing. It was go out and sample a bunch of stuff. I just felt like this is not what I signed up for. This isn't what it is about for me.

P07:1-5 [The worst part was] when I got tested from a multiple choice perspective. I found it horrible when I had to do that because I didn't understand what they wanted. To pick the most correct answer without a certain context because if the context shifted a bit, then it is not A, it is C and I was all about context and I found them inflexible and I don't think they valued my knowledge. They valued something else and I couldn't figure out what the other thing was except maybe they valued their Scantron [multiple choice test scoring cards for machine marking].

P07:1-4 I kind of struggled through some things that just required memorization.

P08:1-4 I realized that regurgitating was not really learning.

P11:1-6 So I'll never know enough biology and that's the fun of it.

The Referential and Structural Aspects of Category CL1

The referential aspects of Category CL1 were determined to include:

- doing biology

When I had my own data I had that sort of ownership over it. It was my project and of course things don't go according to plan but it was a the very end when I started to see, I got it, what research was about because I finally had conclusions that I had carried through to the end and it was when I could finally see a whole bunch of other questions opening up.P06:1-5

- learning independently

I am a very independent learner. I teach myself stuff. I didn't find classroom learning to be something that I enjoyed. And so, it was that independent research that really stuck with me and it was also the field work, being out there. Just observing stuff, seeing stuff and getting interested in things. P0-6:1-5

- consulting specialty experts

I have to link with people who know more than me. I have always known this, that there are a lot of people who know a lot more than I do. So that's kind of how I'm going to learn and I will do it all the way from the web work to meeting people. P11:1-6

The structural aspects of Category CL1 were determined to include:

- experiences with the subject matter

The best experiences I've had were in advanced courses where we could specialize and discuss the subject matter, be allowed to have various interpretations sometimes of the subject matter instead of cramming our brain with things that we have to learn by heart. P05:1-4

- required but not desired elements

I found it horrible when I had to do that [multiple choice tests] because I didn't understand what they wanted. To pick the most correct answer without a certain context because if the context shifted a bit, then it is not A, it is C and I was all about context and I found them inflexible and I don't think they valued my knowledge. P07:1-5
I kind of struggled through some things that just required memorization. P07:1-4

<u>Category L2 - Biology learning is related to the person who guides or mentors the student</u>.

Two different collections of themes of awareness informed the description of this study's second category pertinent to biology learning (Category L2). Based on their primary focus, these themes are:

Category L2 – Themes of awareness collection A – Teacher mentors

Category L2 – Themes of awareness collection B – Being a mentor

The name of this category was derived from the predominant constructs: the people from whom academic biologists learned biology and about doing biology; the academic biologist as a mentor.

Each of the two collections of themes of awareness is described in the following section.

<u>Category L2 – Themes of awareness collection A – Teacher mentors</u>

Academic biologists acknowledge that their high school biology teachers were the ones who gave them a head-start at being successful at learning biology.

P03:1-4 The best was my teacher in honors biology course in grade 12 which was really outstanding. I should go back and visit her. She did a really outstanding job and she engaged many students in biological studies.

P10:1-1 I was very much influenced by one very strong educator in biology so my biology teacher in high school and I had him for two years. [He] very much influenced me. I always had an interest in biology but he certainly continued to nurture that enthusiasm that I had and helped me to continue to pursue that avenue, that interest. So he was very much influential in my experience.

P10:2-3 I got turned on to biology because I had a very good biology teacher especially in grade 10 and 11.

P07:2-3 In grade 13 biology, I had a limnologist, a freshwater biologist, who had a masters in that and actually took us out to lakes. We went out to the field, had to go to the woods, had to actually do something in the greenhouse. He would be the only biology teacher making his students do that, but we really embraced that because there was experiential learning. It wasn't easier. It was actually harder but a lot more enjoyable. He could explain things to us in a way *in situ.*

When considering their personal experiences with learning biology after they graduated from high school, academic biologists make sense of positive relationships with biology professors by seeing these individuals as mentors guiding their way.

Similarly, academic biologists think about renowned biologist in their specialty areas when they speak of people whom they have learned biology from.

P01:1-5 I had a wonderful mentor at [a university] and I guess that it was the mentorship of that professor that probably [guided me]. When I started university I didn't know where I would go. I was probably going into science, actually I thought of being an English major at one point, but that biology professor inspired me in terms of [helping me] see that the frontier was right there. In other words that we know this much but we don't know this and so there was this opportunity of making discoveries and learning that was right there and that's sort of the very best part of that. Certainly it made a big difference to me. It made a big impact on me.

P08:1-1 I did an extra degree which was an honours degree working on a research project with him and that grew into my masters and I did it because I was thrilled with the topic and I was thrilled with working with him and he just was such an excellent mentor. Every day was just such a marvelous day and I was his first graduate student so he was thrilled too.

Category L2 – Themes of awareness collection B – Being a mentor

Academic biologists conceive that mentorship can be theirs to offer in a similar way as it was theirs to have received as part of their education. This perception of the merits of mentorship extends to situations where academic biologists experience interactions with high school students in enriched study programs.

P04:2-12 Essentially it comes down to that: we mesh with students; you click with them, some of them, not all of them. But that often can be the spark for that individual to carry on to get more involved with a particular field. And a lot of the learning, a lot of the outcome, a lot of where students end up, really comes down to those kinds of experiences.

P08: 2-12 What I've got right now is one of the schools is doing student placement thing where they come and work a couple of hours a week with us and we have had a couple of really good students come in, and unfortunately the work is a little menial but then we try to include them in everything else we are doing to so that they can see the excitement of it. Several of them have ended up getting summer jobs here or come in to our [degree] program and are really enlivened so maybe we could find other ways in which we could provide enrichment for [high school] students, maybe not at a whole class level but maybe end up being a few students at a time but it would be wonderful to explore those possibilities to see.

The Referential and Structural Aspects of Category CL2

The referential aspects of Category CL2 were determined to include:

- having good high school teachers

I was very much influenced by one very strong educator in biology, so my biology teacher in high school. I always had an interest in biology but he certainly continued to nurture that enthusiasm that I had and helped me to continue to pursue that avenue, that interest. P10:1-1
The best was my teacher in honours biology course in grade 12 which was really outstanding. I should go back and visit her. She did a really outstanding job and she engaged many students in biological studies. P03:1-4

- having good university professors

I had a wonderful mentor and I guess that it was the mentorship of that professor that probably [guided me].P01: 1-5

- being mentored

I am a big fan of mentoring. I want to have experience with something but I want someone there who can mentor me along the way. I like someone first to give me a basic lesson on understanding, a rather simple exercise allow me to make mistakes but to experiment and hopefully progress with each step and then get feedback along the way with progressively more difficult steps. P10:1-6

- mentoring

What I've got right now is one of the schools is doing student placement where they come and work a couple of hours a week with us and we have had a couple of really good *students come in and we try to include them in everything else we are doing so that they can see the excitement of it. P08:2-12*

The structural aspects of Category CL2 were determined to include:

- passion inspires one forward

I did an honours degree working on a research project with him and that grew into my masters and I did it because I was thrilled with the topic and I was thrilled with working with him and he just was such an excellent mentor. P08:2-12

- relationships determine pathways

We mesh with students, you click with them. Some of them, not all of them. But that often can be the spark for that individual to carry on to get more involved with a particular field. P04:2-12

- heroes

E. O. Wilson is my hero. He has this term called biofilia which is the inherent love of biology and of life and he says it's in all of us. If you look at children even at the youngest ages they just have this affinity for live things and for moving around and being outside and we almost seem to be suppressing that in the way we teach and the way we do things. And I tend to agree with that. P10:1-5

Category L3 - Biology learning is linked to circumstance and opportunity

Two different collections of themes of awareness informed the description of this study's third category pertinent to biology learning (Category L3). Based on their primary focus, these themes are:

Category L3 – Themes of awareness collection A – Serendipity

Category L3 – Themes of awareness collection B – Satisfaction

The name of the category was derived from the predominant constructs: the happenstance nature of the biology learning experiences of academic biologists; leaning along the way.

Each of the two collections of themes of awareness is described in the following section.

Category L3 – Themes of Awareness Collection B - Serendipity

The general sense of academic biologists is that various opportunities are presented to them as they study and train for their careers. Academic biologists link their preparation for their specialty areas with opportunities. They understand that learning biology and learning about biology isn't always based on a unidirectional specific plan of action. Biology learning at the undergraduate level is pre-conceived as completing a series of courses but then re-conceived as doorways to the next level of biology knowledge. Biology learning at the graduate level presents options even beyond that.

P02:1-3 There are so many degrees of freedom and my philosophy is that you just take opportunities that come to you. You don't plan your career path. I really didn't plan it.

P04:1-3 I wish I could say that it had been planned. And this is the experience of most of my colleagues. There are all these things that happen. It is a matter of choices really. You choose to go this way and go that way. Either way would be fine. Chance. It's a fairly significant element I find in academic careers. Opportunities.

P08:1-3 My path has been going through doors as they opened. It wasn't a preconceived path. [Opportunities] shaped me without me choosing where I wanted to go. It all just sounds like serendipity.

P11:1-3 Early in my career, I asked students what they wanted to do, where they wanted to go, what they wanted to pursue. It took me a long time to realize that it really was kind of a silly question. You can advise students and so on. But they, like me, always happen to have opportunities pop up.

Category L3 – Themes of Awareness Collection B - Satisfaction

Academic biologists experience their careers in positive ways. They embrace the circumstances that their studies in biology have placed them in. There are distinct elements of fortune in an academic biologist's conceptualization of the aspects of their career that mesh with learning biology and learning about biology. Biology learning in the Academy is augmentation of previous understanding. It is the penultimate opportunity to learn biology and to continue to learn and do biology.

P10:1-3 I've loved everything that I've done. I continue to love what I do. I have enjoyed every single minute of my experience whether it was from my undergraduate, my graduate experience and my academic work.

P11:1-3 I always followed what I enjoyed and really I don't think anybody told me what to do. The whole area of academic freedom is just exactly what it says. You have the opportunity, the freedom and actually, the tenure at university to do what you want to do. You still have to be productive and so on but you're not given direction. You are self-motivated to do what you enjoy and when you do that and actually accomplish one thing after another, the opportunities just keep popping up. And you choose the opportunity that makes sense to you at the time and for the long term. The good experiences are the exploding of knowledge in your own head and the opportunities that you see that you didn't see before.

Referential and Structural Aspects of Category CL3

The referential aspects of Category CL3 were determined to include:

- embracing opportunities

There are so many degrees of freedom and my philosophy is that you just take opportunities that come to you. You don't plan your career path. I really didn't plan it. P02:1-3

- making choices

I wish I could say that it had been planned. And this is the experience of most of my colleagues. There are all these things that happen. It is a matter of choices really. You choose to go this way and go that way. Either way would be fine. Chance. It's a fairly significant element, I find, in academic careers. P04:1-3
Early in my career, I asked students what they wanted to do, where they wanted to go, what they wanted to pursue. It took me a long time to realize that it really was kind of a silly question. You can advise students and so on. But they, like me, always happen to have opportunities pop up. P11:1-3

The structural aspects of Category CL3 were determined to include:

- chance encounters

My path has been going through doors as they opened. It wasn't a preconceived path. P08:1-3

- academic freedom

I always followed what I enjoyed and really I don't think anybody told me what to do. The whole area of academic freedom is just exactly what it says. You have the opportunity, the freedom and actually, the tenure at university to do what you want to do. You still have to be productive and so on but you're not given direction. You are self-motivated to do what you enjoy and when you do that and actually accomplish one thing after another, the opportunities just keep popping up. And you choose the opportunity that makes sense to you at the time and for the long term. The good experiences are the exploding of knowledge in your own head and the opportunities that you see that you didn't see before. P11:1-3

Depicting the outcome space

The outcome space of a phenomenographic study encapsulates the study's categories of description in one graphic way or other. The researcher must decide on the most appropriate graphic format(s) to use for this purpose based on the need for it (them) to succinctly document variation within the study group's collective understanding of the phenomenon being investigated.

The outcome space in tabular format.

The first format (modified from an outcome space format designed by Boulton-Lewis et al., 2001) through which I have chosen to show this study's outcome space is presented in Table 3. This format includes mention of the referential and structural aspects of the study's categories of description in conjunction with representative quotes. The referential aspects address "what" teaching and learning biology is focused on by academic biologists. The structural aspects address "how" features of teaching and learning biology are focused on by academic biologists.

Table 3: The outcome space: conceptions of biology education held by academic biologists

Predominant Construct	**Category of Description Name**	**Representative Quotes (in italics)**	
		Referential Aspects of the Phenomenon (what is focused on)	**Structural Aspects of the Phenomenon** (how it is focused on)
Curriculum as Instructional Authority	**Category T1**: Biology teaching is bound by discipline-based curriculum and related pedagogy.	**Providing input to curriculum** *Right now we are in the middle of a revamping of the second year biology program so I am involved with one portion of that.* P10:2-2 **Developing course syllabus** *In terms of how it was developed, the modules, all the parts of it were really from the idea of what, so what, now what.* P01:2-10 *So when I first started developing the syllabus for that course I approached other colleagues who I know that teach it and asked them what they found worked and didn't work…so I like to go to people who I respect and find out how they've done it and people who I know are good teachers so that gives me the basis.* P10:2-10 **Considering the student experience** *I tend to make sure I follow up on some of their interests*. P08:2-11 *The projects have to be set up so that they know the headings that are going in to that and then they know what the accumulated score is down to the bottom. And I found that students are quire accepting when you divide up the scores so they know how much they are working for that part of the presentation, oral or written.* P11:2-10 **Considering the professor experience** *All of my best experiences teaching biology have been in field courses.* P05:1-7 *I am fortunate that I am teaching almost exclusively upper year*	**Curriculum oversight** *As chair of the department I have to oversee all of the curriculum matters in biology here.* P05:2-2 **Course autonomy** *It was my own design. I just built around integrating my own material and experience.* P09:2-10 **Course content** *I thought about the content I wanted to deliver, what concepts I thought were important and what concepts were interesting for me.* P03:2-10 **Experience with secondary biology curriculum** *I have never seen high school curriculum before. This was the first time.* P04:2-2 *Zero at the school level. At the university level it's not a provincial formula.* P02:2-2 **Content of secondary biology curriculum** *I thought it was a lot of material for one course. It certainly seems like a first year university course in terms of, I think our university first year biology courses cover a lot of the same stuff.* **Time and resources for doing biology/engaging with biology** *I thought that the [secondary biology curriculum] was difficult to get a lot of experimental hands on in some cases and was wondering, as I went through it, how I would keep the students engaged.* P01:2-1 **Need for general biology literacy**

		level courses so they tend to be smaller class sizes and so I can afford to take students with me out to the field P10:1-7 **Understanding suggested teaching strategies in the secondary biology curriculum** *I would not know how to teach biology and I would probably violate several of the concepts there, trying to move forward.* P07:2-1	*One of the things [is] the importance of educating [in] biology for a responsible citizenship having a foundational understanding of the importance of biology to their everyday lives, environmental issues, health issues.* P05:2-5.
Instructional Environment as a Factor of Variation	**Category T2**: Biology teaching varies between the secondary and tertiary levels of the education system.	**Addressing gaps** *Since my background is plants, I thought it was a little light on the plants, a little heavy on humans.* P01:2-1 *The things they call experiments are just observational.* P07:2-2 **Emphasizing knowing biology** *I am very interested in understanding and I get my students to create flow charts of what they learn and what comes from what.* P07:2-11 **Emphasizing doing biology** *Instead of memorizing, actually work with their hands and bring all of their sense to the information. So if you can get the students to use all of their sense then they will be able to remember this stuff and be able to build on it.* P11:2-4 **Acknowledging skill deficits** *[The teachers] are not comfortable with plants so they just avoid covering them.*P08:2-6 **Coping with testing and evaluating** *Well I think my disappointment with high school curriculum is [teachers] are trapped in to doing what is necessary because there is going to be testing at the end of the day and that leads to preparing for the test.* P07:2-12 **Addressing curricula overlap** *These kids should have gotten all that in high school but then we go through that process and we give it to them again. Maybe it is good to repeat this. I was quite*	**Qualities of secondary biology curriculum** *It takes a classical approach to biology.* P01:2-1 *I think the high school preparation as it is described there is good.* P04:2-4 *The focus is mainly on human biology and is very restricted to animal biology and the perspective on so called diversity is not very diverse.* P02:2-1 **Teacher background** *I don't know whether all of the teachers now who teach biology all have a good biology background.* P01:2-3 *I am not criticizing the people who are teaching biology and don't have the background because they have been put in that situation and all the ones I have talked to say that they wish to goodness that they did have more background.* P08:1-11 *I don't know who had the crazy idea of allowing people to teach whatever is needed instead of getting them to teach in their specialty.* P09:2-11. **Instructional resources to support teaching** *There are opportunities in this curriculum for teachers to be fairly creative however I would worry about them being constrained both by their own experience and by materials in the high school.* P01:2-3 **Potential for collaborations** *I would like high school teachers*

		*struck by that. If I looked at that curriculum and I knew that the students coming into the university system had that stuff down, I would be looking a doing something completely different than what we do now in university.*P04:2-1 **Defining teaching excellence** *If you can have people integrate the knowledge they are given with the day to day tasks that they are doing into something that is fundamentally better than either of those two things then than is probably the most important aspect of learning in biology.* P05:1-9	*to be able to make use of faculty members in various topics to get excited, to come up with ideas, to come into their classes, to do whatever would be good and not in a remedial way or in a critical way or somehow thinking they are not doing a good enough job on their own because they have far more to do than we do especially in teaching load.* P08:2-12 **Assessment** *I did not particularly enjoy marking. I would rather leave that stuff out but the system required that you did things to make it work. That's what I really least enjoyed because nobody is learning when you do that.*P11:1-8
Experience as a Factor of Influence	**Category T3**: Biology teaching is an extension of academic biologists' own experiences with biology as a study subject, as a science discipline and as a career.	**Perfecting approach over time** *Each year was a response to what happened in the previous year so it was illustrating my growth as a facilitator of learning.* P08:2-10 *Well actually it took me a while to really succeed with students.* P09:1-7 **Teaching from example** *I really learned how a PhD program shouldn't be and how not to be a supervisor [because] my supervisor did a fair bit of teaching and was a horrible teacher.* P08:1-1	**Influence of life experiences** *I was already quite engaged in biology, even before high school because my father had a farming background and was always very interested in farming and agriculture and forestry so I was quite biologically aware.* P03:1-1 **Influence of school experiences** *[High school]* was very much ecologically based. It was investigative, going into ponds, that sort of things. Capturing, getting water samples. Getting soils samples. There was a lot of aquatic biology. I certainly enjoyed the aquatic part of it. In fact, I took an advanced limnology course in university probably as a result of that. P01:1-4 *In my undergrad I took my first course. Just the way it was taught. The prof was very experiential. We might have had three or four lectures in the entire course. Most of it was self-discovery and interaction one on one with the professor, and doing.* P05:1-5

Action Related to Preferences	**Category L1**: Biology learning results from doing biology through preferred process and place.	**Doing biology** *When I had my own data I had that sort of ownership over it. It was my project and of course things don't go according to plan but it was a the very end when I started to see, I got it, what research was about because I finally had conclusions that I had carried through to the end and it was when I could finally see a whole bunch of other questions opening up.*P06:1-5 **Learning independently** *I am a very independent learner. I teach myself stuff. I didn't find classroom learning to be something that I enjoyed. And so, it was that independent research that really stuck with me and it was also the field work, being out there. Just observing stuff, seeing stuff and getting interested in things. 0-6:1-5* **Consulting specialty experts** *I have to link with people who know more than me. I have always known this, that there are a lot of people who know a lot more than I do. So that's kind of how I'm going to learn and I will do it all the way from the web work to meeting people.* P11:1-6	**Experiences with the subject matter** *The best experiences I've had were in advanced courses where we could specialize and discuss the subject matter, be allowed to have various interpretations sometimes of the subject matter instead of cramming our brain with things that we have to learn by heart.* P05:1-4 **Required but not desired elements** *I found it horrible when I had to do that [multiple choice tests] because I didn't understand what they wanted. To pick the most correct answer without a certain context because if the context shifted a bit, then it is not A, it is C and I was all about context and I found them inflexible and I don't think they valued my knowledge.* P07:1-5 *I kind of struggled through some things that just required memorization.* P07:1-4
Individuals of Motivation and Influence	**Category L2**: Biology learning is related to the person who guides or mentors the student.	**Having good high school teachers** *I was very much influenced by one very strong educator in biology, so my biology teacher in high school. I always had an interest in biology but he certainly continued to nurture*	**Passion inspires one forward** *I did an honours degree working on a research project with him and that grew into my masters and I did it because I was thrilled with the topic and I was thrilled with working with him and he just was such an excellent*

		that enthusiasm that I had and helped me to continue to pursue that avenue, that interest. P10:1-1 *The best was my teacher in honours biology course in grade 12 which was really outstanding. I should go back and visit her. She did a really outstanding job and she engaged many students in biological studies.* P03:1-4 **Having good university professors** *I had a wonderful mentor and I guess that it was the mentorship of that professor that probably [guided me].*P01: 1-5 **Being mentored** *I am a big fan of mentoring. I want to have experience with something but I want someone there who can mentor me along the way. I like someone first to give me a basic lesson on understanding, a rather simple exercise allow me to make mistakes but to experiment and hopefully progress with each step and then get feedback along the way with progressively more difficult steps.* P10:1-6 **Mentoring** *What I've got right now is one of the schools is doing student placement where they come and work a couple of hours a week with us and we have had a couple of really good students come in and we try to include them in everything else we are doing so that they can see the excitement of it.* P08:2-12	*mentor.* **Relationships determine pathways** *We mesh with students, you click with them. Some of them, not all of them. But that often can be the spark for that individual to carry on to get more involved with a particular field.* P04:2-12 **Heroes** *E. O Wilson is my hero. He has this term called biofilia which is the inherent love of biology and of life and he says it's in all of us. If you look at children even at the youngest ages they just have this affinity for live things and for moving around and being outside and we almost seem to be suppressing that in the way we teach and the way we do things. And I tend to agree with that.*P10:1-5
Multiple Discovery	**Category L3**: Biology learning is linked to circumstance and opportunity.	**Embracing opportunities** *There are so many degrees of freedom and my philosophy is that you just take opportunities that come to you. You don't plan your career path. I really didn't plan it.* P02:1-3 **Making choices** *I wish I could say that it had been planned. And this is the experience of most of my colleagues. There are all these things that happen. It is a matter*	**Chance encounters** *My path has been going through doors as they opened. It wasn't a preconceived path.* P08:1-3 **Academic freedom** *I always followed what I enjoyed and really I don't think anybody told me what to do. The whole area of academic freedom is just exactly what it says. You have the opportunity, the freedom and actually, the tenure at university to do what you want to do. You*

		of choices really. You choose to go this way and go that way. Either way would be fine. Chance. It's a fairly significant element, I find, in academic careers. P04:1-3 *Early in my career, I asked students what they wanted to do, where they wanted to go, what they wanted to pursue. It took me a long time to realize that it really was kind of a silly question. You can advise students and so on. But they, like me, always happen to have opportunities pop up.*	*still have to be productive and so on but you're not given direction. You are self-motivated to do what you enjoy and when you do that and actually accomplish one thing after another, the opportunities just keep popping up. And you choose the opportunity that makes sense to you at the time and for the long term. The good experiences are the exploding of knowledge in your own head and the opportunities that you see that you didn't see before.* P11:1-3

The outcome space in diagrammatic format.

The second format (modified from an outcome space format designed by Marton and Pong, 2005) through which I have chosen to show this study's outcome space is presented in Figure 2. This format represents a hierarchical structure of the study's categories of description. It illustrates the degrees of variation of understanding that academic biologists in my study group have of biology education as identified through the complexities represented by each of the categories of description. It also illustrates the links that my study identifies between academic biologists' conceptions of teaching biology and their conceptions of learning biology.

By holding the pinnacle position in the hierarchy, Category T1 represents the most complex understanding of biology teaching. It is inclusive of all of the other expressions of conceptualization that academic biologists have of both teaching and learning biology. The position in the hierarchy occupied by Category T2 indicates a less complex understanding of biology teaching than Category T1 but an understanding that shows a relatively complex awareness of biology learning as well. And finally, the position in the hierarchy occupied by Category T3 indicates the least complex understanding of biology teaching but one that is linked with the full breadth of understanding that my study group have of biology learning.

The positions occupied by the categories of description that represent conceptions of biology learning (i.e. CL1, CL2, CL3) illustrate that academic biologists have less breadth of understanding of their experiences with biology learning than of their experiences with biology teaching. As well academic biologists conceive their preferences of learning biology in a more complex way than they conceive who or what has influenced their biology learning and what or where they have learned biology.

Despite it representing a hierarchy of conceptions, it must be noted that this diagrammatic format of the study's outcome space should not be perceived as passing judgement on better or worse ways for academic biologists to conceive biology education. No one conception is superior to another but one conception may represent a greater breadth of understanding than another.

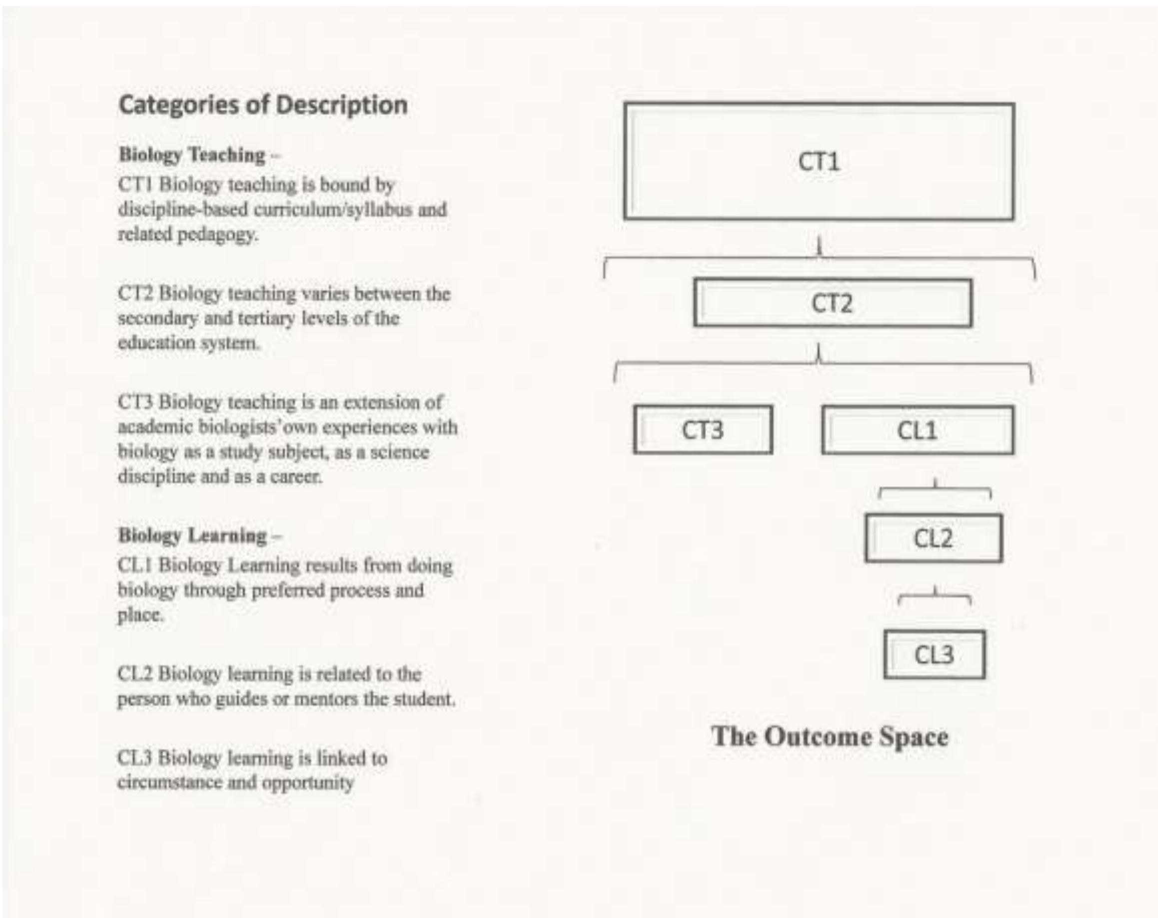

Figure 2: The outcome space: conceptions of biology education held by academic biologists.

In the next chapter I will indicate how my results answer the guiding questions of my study and what implications they have for secondary biology curriculum and academic biologists' and high school biology teachers' associations with that curriculum. I will discuss my findings as they relate to components of my literature review and I will acknowledge the concerns I have about comparing research from a first order perspective with findings from a second order perspective. I will conclude the chapter by identifying the additional questions that my study has generated about biology education as a phenomenon of research interest.

Chapter 5 Discussion and Conclusion

> Conceptions are generally beyond the realm of discussion and interrogation and are often at a level not perceived to be in need of evaluation. They are quoted rarely and infrequently identified, but they constantly coerce our speech, thought, and social arrangements. Conceptions are the by-products of our thoughts, experiences, education, culture, history, and the ideals and values that society insists on so that we can actively participate. Why is it necessary to expose the intellectual map that is our experience? The answer lies within the fact that conceptions determine our judgement, direct our inquiry and are the explanations for our everyday lives and practices. (Barnard, McCosker & Gerber, 1999, p. 218)

Here is the outcome space – is that all there is?

Phenomenographic studies are typically finished when the outcome space is generated. Little discussion of the outcome space is expected in a phenomenographic report because the outcome space represents a collective intellect and thereby is already an interpretation of reality, ideas, beliefs, facts and understanding of the phenomenon in question. There is no further interpretation required of the researcher (Bowden, 1994; Barnard, McCosker & Gerber, 1999; Alsop & Thompsett, 2006). The outcome space completes the exploration of the how (structural) and what (referential) aspects of people's conceptions of a phenomenon although it is not meant to represent an explanation of why those conceptions are held (Marton, 1981; 1986).

These clarifications of the place held by the outcome space in phenomenography explain why my intention was to consider my study finished when its outcome space was revealed. It was never my goal to conduct a study that would identify what is wrong with biology education (particularly the secondary biology curriculum) and to seek results that would prescribe a fix for the problem(s). Instead, because "I believe we need to look at teaching and learning from the perspective of how those engaged in teaching and learning see it" (Prosser, 1994, p. 39), my intention was solely to take "account of the individual perceptions of those involved in the teaching and learning process"(Prosser, 1994, p. 39). I felt my study would be useful because before the outcome space of my study was revealed, there was no account of the perceptions of academic biologists about biology education. This represented a gap in understanding since academic biologists are certainly individuals involved in the biology teaching and learning process. The outcome space of my study has implications for the areas of biology education that academic biologists have conceptions of. Those implications will be presented in a later section of this chapter.

Answers in the outcome space

My study's outcome space provides answers to the overarching focus question of my research (A) and the first two subsidiary questions (a, b). Worded in the way of phenomenography, where the "what" and the "how" aspects of a group's conceptions of a phenomenon are the matters being researched, these questions were:

A. **What** conceptions of teaching and learning biology are held by academic biologists?

a. **How** do academic biologists experience learning biology?

b. **How** do academic biologists experience teaching biology?

Collectively, the outcome space of my study describes the range of different ways members of my study group conceive biology education which includes conceptions of how they experience learning and teaching biology. If I transfer the outcome space from a visually depictive format (i.e. as it is shown in Table 3 and Figure 2) to a textually descriptive format, I am able to encapsulate this variation of understanding as follows:

Academic biologists conceive curriculum as the instructional authority of biology education. They experience curriculum development through their institutions and through the design and implementation of their course syllabi. When planning the structure of their own courses, they consider the student and the content in light of their own expertise with the subject area and the requirements of their institutions. They have awareness of pedagogy but acknowledge their lack of familiarity with the education theory, the language and the instructional strategies that drive it. They understand biology teaching through their own experiences as a student and through their role as professors in the Academy. They think about learning biology as part of their life experiences. To them, learning biology is doing biology. They do biology with their students to learn. They do biology with their peers to learn. They express a passion for their work which they believe is important to share with their students.

Furthermore, through their understanding of knowing biology and doing biology, academic biologists hold views of biology teaching and learning at the secondary and tertiary level of the education system. They discern the role of the biology teacher and/or biology professor as being a critical factor in the biology learning experience of biology students in high schools and in universities. A commonly held viewpoint is that biology teachers must engage their students. They acknowledge the contributions of their own biology teachers and professors. They hold the opinion that biology teachers in high schools need to know about biology and about doing biology. They retain the perception that this teacher competency needs to be supported by resources and a plan for curriculum implementation that has an experiential focus. The actualization of competency in biology teaching and learning is viewed by academic biologists as involving mentoring, being mentored, embracing opportunities, making choices and having the advantage of academic freedom.

This descriptive encapsulation of the outcome space of my study serves as a precursor to the following sections in which I will address two related topics:

- the way in which the outcome space answers the third subsidiary question that guided my research (c);
- the tenets of phenomenography which make me question the way that phenomenographers are able to compare their work with that of researchers who use other qualitative research methodologies.

Implications of the outcome space.

The last of the subsidiary questions that guided my research was:

c) Are there any implications of academic biologist's conceptions of teaching and learning biology for secondary biology curricula?

My study's outcome space provides an answer for this question that is pertinent to the secondary biology curriculum development process, to academic biologists themselves, and to biology teachers as elaborated upon below.

Implications for the secondary biology curriculum development process.

The outcome space of my study has implications for the secondary biology curriculum process but it is necessary to first understand how that curriculum is typically derived. At the present time, secondary biology curricula in Canadian provinces are based on the Pan Canadian Common Framework of Science Learning Outcomes, K to 12. In the various regions of the country, common curriculum agreements fall under the auspices of provincial departments of education. Subject area teachers in each province serve on curriculum development advisory committees which provide input when any science curriculum is being revised. The biology curriculum documents for Biology 112/111 and Biology 122/121 in New Brunswick culminated from the decisions made at all of these levels of administration, particularly the teacher advisory committee level. I served on that committee.

The Biology 112/111/ and Biology 121/121 curriculum documents in New Brunswick are produced in the form of guides for secondary biology teachers in the province to use in the outcomes framework for high school biology courses. They include suggestions to assist biology teachers in designing biology learning experiences and in developing associated assessment strategies. As indicated on the first page of each of these curriculum documents, the recommendations for instruction are focused on scientific inquiry (NBDED, 2008). No elaboration on the scientific inquiry teaching is provided there, however.

Scientific inquiry is an aspect of science education that is backed by a thorough and continually updated research literature, albeit one that concentrates on K-12 students, in-service teachers and pre-service teachers. Depending on researcher perspective, the studies represented in this literature are variously classified (i.e. these terms are used interchangeably) as inquiry science, inquiry based learning, guided inquiry or teaching science through inquiry or teaching science as inquiry (Windschitl, 2003). No matter the terminology used, teaching inquiry science (e.g. biology) means arranging for students to have subject related experiences that cause them to ask questions. It means allowing time for students to investigate those questions and generate follow-up questions. Teaching science through inquiry also allows students to have time and resources to be able to plan and implement a strategy to answer those questions. As put by Crawford (2007),

> A key aspect of teaching science as inquiry is one of allowing students extended time to really grapple with data and to make sense of their observations, using logic and reasoning. Thus, in analyzing the nature of a teacher's instructional approach, it is important to ask, how does this teacher support students in using data as evidence? The emphases on grappling with data and the use of evidence goes beyond answering topic-centered questions, such as ''What is a cell?'' and ''What is the name of that bird?'' to developing explanations to questions, such as ''Why should I take all of my prescribed antibiotic when I am sick?'' and ''Are robins arriving in my backyard earlier each spring and why?'' (p. 618).

Through this description of inquiry science teaching, Crawford (2007) is essentially summarizing the conception that my study's outcome space has determined academic biologists have of a preferred secondary biology curriculum. It would be a curriculum that represents what doing biology involves as opposed to a curriculum that centers on introducing biology students to stand-alone units of biological concepts and taking part in activities (including lectures) meant to illustrate those concepts (Schwandt, 1994). The outcome space of my study implies that in a secondary biology curriculum preferred by academic biologists, doing biology would result in learning biology.

Hodson (1986) supports the concept of learning science by doing science. He holds the view that in order for science students to learn science, they need to have opportunities to use the methods and processes of science to investigate phenomena, solve problems and ask questions about what intrigues them about the phenomena. The outcome space of my study implies that Hodson's (1986) view translates well to academic biologists' understanding of how biology should be taught and what biology should be taught to biology students in high school.

The corresponding implication of my study's outcome space is that the secondary biology curriculum should clarify what is meant by science inquiry both for biology teachers and for biology students. In the Biology 112/121 and Biology 122/121 curriculum documents, science inquiry should be clearly understood as teaching and learning biology through knowing biology and doing biology. Academic biologists share the point of view that secondary biology curricula should move from being driven by disconnected chunks of content to being driven primarily by experiences that revolve around student generated questions with a focus on an experiential (i.e. students do, teachers facilitate), investigative approach to finding answers to those questions. My study's outcome space shows that academic biologists conceive this form of science inquiry, implemented through a secondary biology curriculum, as one that would benefit students who intend to go on in biology at the university level. They conceive that it would also improve the biological literacy of students who end their formal biology learning after their high school education.

Implications for academic biologists.

The second implication of my study's outcome space on the secondary biology curriculum relates to the issue of academic biologists' involvement in its development and periodic revision. Category T1 in my study's outcome space addresses the understanding that academic biologists have of how the secondary biology curriculum is framed, particularly the curriculum contents and of the recommendations for delivery of that content to high school students. Category T2 in my study's outcome space addresses academic biologists' views of learning the secondary biology curriculum content and of their experiences with students who have studied biology through that curriculum. Within my study's outcome space, these two categories of description outline the degree to which academic biologists typically experience the secondary biology curriculum. This level of awareness, which academic biologists indicate is minimal, might be considered a missing factor in secondary biology curriculum development although there is no part of my study's outcome space that includes academic biologists' conception of their participation in the secondary biology curriculum development process either at the national level or at the provincial level or both. It is not an experience they are familiar with.

The science education literature that describes decision making about curriculum (Drayton & Falk, 2006; Kim & Fortner, 2007) relates to what my study's outcome space reveals as academic biologists' conceptions about the development of secondary biology curriculum. Morrow (2003) acknowledges positive experiences with scientists developing curriculum guides for science teachers. She is of the opinion that scientists are discipline experts and can thus provide advice about authentic science content and process, no matter that scientists seldom have full understanding of the school environment where the curriculum guides will be used. In contrast, Jenkins (2008) and also Ritter (2008) express disapproval when commenting on scientists being involved in any matters related to school science curriculum. These two science education researchers perceive scientists to have narrow specialties that do not equip them with the ability to contribute to the development of a generalized science curriculum.

Other science education researchers support the argument that science teaching is most appropriate if the focus is on students understanding nature of science (NOS). They claim that NOS defines how science works and that science teaching through NOS builds scientific literacy because it allows science students to know what science is, to be aware of how science knowledge comes to be accepted and to realize what science can and cannot do (Clough & Olsen, 2004). Also, these science education researchers suggest that because a scientist has a narrow area of expertise, he or she is not the best candidate for a science curriculum development team (Mccomas, 1998; Adb-El-Khalick & Lederman, 2000).

There is likewise the perspective described in science education literature that scientists encounter barriers that they must overcome to be involved with science education beyond the Academy, including curriculum development for school science. As noted by Ecklund, James and Lincoln (2012), the professional culture that is normally experienced by university scientists is one that values research productivity over all other types of contributions to the institution. Outreach in the form of collaboration with science teachers or committees involved with science curriculum development exercises is not deemed as a critical component of a scientist's work. Indeed, academic biologists' experiences with biology curriculum beyond the Academy are not a dominant aspect of my study's outcome space.

Overall, when consideration is given to the perspective of the science education researchers that dispute or support the involvement of scientists in school science curriculum development, it would seem that decisions about this matter continue to be made on the basis of personal choice and that they are related to a scientist's willingness to donate his or her expertise. My study's outcomes space suggests that decisions about the role of academic biologists in secondary biology curriculum in particular are likely to be made on a case by case basis.

Implication of for teachers of the secondary biology curriculum.

An additional implication of my study's outcome space involves the teaching of the secondary biology curriculum.

To begin with, the outcome space of my study implies that in order for instructional strategies that focus on science inquiry to result in students knowing biology and doing biology in high school biology courses, secondary biology teachers need to know the biology that is in the secondary biology curricula and they need to be able to do that biology. Academic biologists conceive that this is not always the case and so do science education researchers like Windschitl (2003) who believes that even though inquiry is held to be the quintessential experience of science, the vast majority of preservice science teachers, including those who intend to teach secondary biology courses, enter their teacher preparation programs without having conducted a single inquiry in which they have developed a question of interest to them and then designed the investigation to answer that question. In other words, research shows that preservice science teachers have rarely done science and therefore feel unprepared to lead students in formulating questions, designing experiments and representing data. As a result, they seldom facilitate their students having experiences that initiate inquiry based science lessons (Trautman & MaKinster, 2005; Jeanpierre et al, 2005). This challenge with implementing science curricula through science inquiry in schools is compounded by the fact that few teacher preparatory programs at universities offer pre-service teachers an opportunity to ask serious scientific questions, design original experiments, collect significant experimental data, conduct meaningful analysis and evaluate their findings against their hypothesis (Haakonsen et al., 1993; Melear et al., 2000; Kahle & Kronebusch, 2003).

Beyond these considerations about the abilities of science teachers to implement science curricula through inquiry, the outcome space of my study revealed that academic biologists have a perception of the influence that teachers have on students' success with learning biology, particularly when it comes to preparing students for introductory biology courses. Secondary biology teachers are held in high regard by academic biologists. However academic biologists believe that biology teachers need to have a sound background in biology with which to involve students in doing the biology that is in the secondary biology curriculum. Academic biologists also perceive that having an undergraduate biology degree as a precursor to having an education degree is not a guarantee that a biology teacher knows how to do biology. But academic biologists do not have any conceptions of an undergraduate biology degree program being one that provides expertise in biology teacher training. Nor do academic biologists conceive that the subject matter content they engage their students with is what will be dealt with to some degree by biology students who intend to become biology teachers in secondary schools. This compartmentalization of biology as a science subject area and biology as a science discipline substantiates the focus of the science teacher education research of Deng (2007) who says that:

> A secondary-school science subject can be defined as a study or a course of study in the curriculum, in which the subject matter is selected, organized, and formulated for the purpose of teaching and learning. Many secondary-school science subjects—such as physics, chemistry, and biology—are conceptualized along disciplinary lines, bearing the same names as their parent academic disciplines. An academic discipline of science is referred to as a branch of learning associated with a particular department of science at the university, in which the subject matters are arranged and formulated primarily for the purpose of scientific inquiry and preparing future scientists.

Knowledge of subject matter content is part of what Shulman (1986) describes as pedagogical content knowledge. This knowledge is unique to teachers and concerns the manner in which teachers relate their knowledge about teaching (pedagogical knowledge) to their knowledge about the subject they are teaching (their content knowledge). Cochran, King and DeRuiter (1991) add to Shulman's point of view by noting that:

> Pedagogical content knowledge is that form of knowledge that makes teachers teachers rather than subject area experts. Teachers differ from biologists, historians, writers, or educational researchers, not necessarily in the quality or quantity of their subject matter knowledge, but in how that knowledge is organized and used. For example, an experienced science teacher's knowledge of science is structured from a teaching perspective and is used as a basis for helping

students to understand specific concepts. A scientist's knowledge, on the other hand, is structured from a research perspective and is used as a basis for the construction of new knowledge in the field (p. 5).

In terms of pedagogical content knowledge, when biology learning happens, secondary biology teachers use their own understanding of biology concepts and their own experiences with doing biology to transform secondary biology curriculum content in such a way that it can be understood by biology students. Although the outcome space of my study does not reveal an understanding of academic biologists of pedagogical content knowledge per se, given the perception that academic biologists have of what constitutes excellence in biology teaching and learning, it would seem that academic biologists expect that in order to demonstrate excellence, biology teachers need to transform the subject matter of secondary school biology courses so that their students do biology to learn and understand biology.

Another implication of my study's outcome space is related to academic biologists' interactions with biology teachers in schools and their willingness for collaborations to be ongoing. In the interest of biology teachers acquiring a more complete understanding of a biology research environment and the ways that biological findings are derived (in essence, in the interest of biology teachers augmenting their biology pedagogical content knowledge), academic biologists perceive that collaborations between secondary biology teachers and academic biologists are worth pursuing.

Comparing my outcome space with existing science education literature

As already noted, I was unable to locate any reports, in the science education literature, of phenomenographic studies (i.e. research with a second order perspective) like mine. There have only been reports about related studies with a first order perspective. This dichotomy raises a concern. It has made me unsettled about identifying the aspects of my study's findings that extend or challenge the knowledge that I identified in my literature review.

The primary issue is with the appropriateness of declaring that my study's results support, contravene or augment research that was conducted through first order methodology. I am wondering if I would change to being a first order perspective researcher if I made such declarations.

My apprehension is somewhat substantiated by Larsson and Holmstrom (2007) who point out how different the results of a study are when data about a particular phenomenon (e.g. anaesthesiologists' conceptions of their work) are analyzed through phenomenology and then also through phenomenography. Boulton-Lewis et al., (2001), note that it is even difficult to expect accurate comparisons to be made when all studies in question are phenomenographic because of the confusion about or different interpretations of the processes for this methodology. Sometimes it is only the data collection process that is done through pure phenomenography. The data analysis process might be accomplished through phenomenology, grounded theory or mixed method (Samuelowicz & Bain, 1992; Trigwell & Prosser, 1996; Kember, 1997; Wlodarsky, 2005; Bush et al., 2011). So other phenomenographers acknowledge the risk of comparing apples with oranges when attempts are made to draw relationships between phenomenographic studies and those that use other qualitative research approaches.

To make a final point, while I realize that the traditional format of reporting the results of one's research involves making links with other literature about the subject of the study, by choosing phenomenography, I was assuming a position of trust with my study group members and thus pledging to organize and map their collective conceptions of biology education. Phenomenography makes no judgement on the perception of individuals. This means that a phenomenographer must consider the appropriateness of assessing the relationship of his or her findings with the broad domain of science education literature.

Further questions

This study has generated additional questions that I feel are worthy of investigation through phenomenography so that more is known about the full spectrum of biology teaching and learning through the various levels of the education system. They include:

- what conceptions do secondary biology teachers have of biology teaching and learning?
- what conceptions do science educators in university education faculties have of biology teaching and learning?
- what conceptions do provincial education departments have of biology teaching and learning?

- what would the outcome be if Variation Theory was applied to the outcome space of my study in an attempt to determine why conceptions of academic biologists are what they are?
- how do phenomenographers conceive their second order research findings in relation to findings from related first order studies?

Concluding the reflection

The initial stimulus of this study was self-reflection and the interest of a phenomenographer, a biologist, a biology teacher and a science educator, in academic biologists' understanding of biology teaching and learning. My reflections were focused on my belief that it is important to identify variation in the way phenomena are seen because it will help to clarify the factors that influence an individual's learning. My aim, therefore, was to encourage academic biologists to reflect on biology education based on the dimensions of their experiences with it. I wanted to know if there were implications of academic biologists' conceptions of biology education for the secondary biology curriculum, a curriculum that I helped develop and teach in New Brunswick.

The outcome space of my study has augmented my own conception of biology teaching and learning particularly how it fits with secondary biology curriculum development, secondary biology teacher preparation programs and of the role that science educators have in those programs. But that is the nature of learning. As a result of undertaking this study, my awareness is different. My conception has changed. I have learned. This is typically the revelation of phenomenography.

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APPENDIX I

Questions for Interview 1

<u>Background to the Phenomenon</u>

1. Please tell me about your own background biology education, beginning with high school.
2. How long have you worked as an academic biologist? What type of biology do you specialize in?
3. From your present standpoint, what, if anything would you change about the education path you followed to become an academic biologist?

<u>Focusing on Learning and Teaching Biology</u>

4. Please tell me about the best and worst experiences you remember about studying biology in high school.
5. Please tell me about the best and worst experiences you remember about studying biology in university.
6. If you were now to set out to study some aspect of biology that you don't know much about currently, how would you do so?
7. Please tell me about the best experiences you can remember about teaching biology.
8. Please tell me about the worst experiences you can remember about teaching biology.
9. What represents excellence in biology teaching to you?

10. Do you feel that this differs if it is a high school setting rather than a university setting?

<u>Summing Up</u>

11. Is there anything else you would like to add to what we've already discussed about your experiences with teaching and learning biology?

Thank you for this time today. I am going to leave you with a document to review as the basis for our next interview. It is either the grade 11 or grade 12 New Brunswick high school biology curriculum, which is an example of what high school biology teachers in Canada would be expected to deliver to high school students enrolled in college preparatory programs at the secondary level. I would also like to ask you to share a course syllabus with me. Would you please email that to me between now and when we do the second interview.

APPENDIX II

Questions for Interview 2 (Task Oriented)

When we last met we talked about your education and career path and your personal experiences with teaching and learning biology. I left you with the New Brunswick high school biology curriculum to peruse so I would like to tie into where we left off at the end of the first interview by beginning today's conversation with a focus on that document.

<u>Specifics of Task 1</u>

a. Would you please share your overall impressions of this document with me?

b. What are your prior experiences with biology curricula?

c. What memories or thoughts does this document bring back to you about your own biology classes in high school?

d. Based on the biology teaching and learning experiences you've had until this point in your career as an academic biologist, what aspects of this curriculum do you think prepare high school students for an introductory university biology course and/or a career in biology?

e. Do you find that there are themes or concepts missing from this curriculum that you think should be taught in high school? What makes you say this?

f. Do you find that there are any themes or concepts in this curriculum that shouldn't be there at all? What makes you say this?

g. If a curriculum development committee asked for your opinion about revising this document what would you say to them?

h. What advice would you give to a biology teacher who would be teaching this curriculum?

Specifics of Task 2

i. Imagine yourself as a high school biology teacher. How would you go about teaching your grade 12 students this particular curriculum component (as worded in the document that you've just reviewed)?

Demonstrate an understanding of genetic modifications found in a variety of organisms either through naturally occurring processes or through intervention by humans. (Biology 12 - NB Curriculum Guide, 2008, p28).

Specifics of Task 3

j. I have asked you to share a course syllabus with me and thank you very much for sending that to me through email. I wonder if you would tell me a bit about what went in to the creation of that syllabus?.

k. How would you compare that course curriculum of yours with what is in the New Brunswick high school biology curriculum document?

Summing Up

l. Is there anything you would like to add to what we've already discussed about your experiences with teaching and learning biology?

Thank you for agreeing to speak to me and share your thoughts and opinions. I very much appreciate the time that you have made available for our conversations.

APPENDIX III

Date

Dr. _______
Department of Biology
_____ University
Address

Dear Dr. _______,

This purpose of this letter is to invite you to participate in research that I am conducting as part of my doctoral dissertation in science education. The focus of my work is the conception that academic biologists like you, have about biology education. The information that I collect will be used in my doctoral dissertation and in possible future academic publications.

The research will be done through two individual interviews, each of which will involve a conversation between you and me about your experiences with biology teaching and learning. The interviews can be done at a time of your choosing and will each last less than an hour. Each interview will be audio-recorded. The information I collect will be for research purposes only. You will not be identified by name when information is analyzed or in any reports, publications or presentations that come from the study. No information will be released that might allow you to be identified personally.

Please understand that your participation in my study is voluntary, and that you may withdraw from the research at any time. You may also withdraw any information you have provided, without penalty, up to one month after the interviews have taken place. That said, I believe that you will find the interviews interesting and the whole experience a positive one.

I am attaching an information sheet that answers some of the questions you might have about this study.

I am also attaching a consent form for you to complete if you agree to be a study participant.

I look forward to receiving your reply about this request.

Yours sincerely,

Debby Peck
PhD Candidate
Faculty of Education
University of New Brunswick

CONSENT FORM for Study Participants (Academic Biologists)

Title of Dissertation Research: Academic Biologists' Conceptions of Biology Education

Researcher: Ms. Debby Peck, PhD Candidate, Faculty of Education, University of New Brunswick

CONSENT:

I, ____________________________________ , agree to participate in this study.

(please print your name on the line)

Your signature:

Date:

Thank you very much. Ms. Peck will make arrangements to pick up this form.

If you would like a summary of the results of this research, please provide your mailing address below:

Curriculum Vitae

Name:

Deborah Elinor Peck

Universities attended:

University of New Brunswick	PhD candidate, 2008 – 2015
University of New Brunswick	MSc, 1987
University of New Brunswick	BEd, 1979
University of New Brunswick	BSc, 1976

Publications:

(1984). Peck, D.E., Cumming, B.G., *In vitro* propagation of Begonia X tuberhybrida from leaf sections. *HortScience.* 19(3), 395-97.

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(2015). Sullenger, S.E. & Peck, D., Studying science after school. In: K.S. Sullenger & R.S. Turner (Eds.), New Grounds- Pushing the boundaries of studying informal learning in science, mathematics and technology (pp. 247-268). Bold Visions in Educational Research, 46. Rotterdam: Sense Publishers

Conference Publications:

(2008, March). Enhancing science understanding for middle school students through interactions with a field botanist. Peck, D., & Sullenger, S., NARST Conference, Baltimore, MD.

(2009, January). Collaboration between teachers and scientists: the impact of EcoAction. Peck, D. & Sullenger, S., ASTE Conference, Hartford, CT.

(2009, March). Writing for communicating and understanding ecology field experiences in middle school. Peck, D., & Sullenger, K., NSTA Conference, New Orleans, LA.

(2009, May). Exploring place and learning science: connecting students and the community of science. Sullenger, K., & Peck, D., 5WEEC , Montreal, QE.

(2009, September). Transitioning between professional identities: our journey to becoming science educators. Peck, D., & Barker, S., EDGE Conference, St. John's, NL.

(2010, March). Exploring middle school students' sense of place and engagement in science learning. Peck, D. & Sullenger, S. NARST Conference, Philadelphia, PA.

Academic Awards:

(2007). CRYSTAL Atlantique Research Award for Doctoral Candidates from the National Science and Engineering Research Council (NSERC)

(2008). CRYSTAL Atlantique Research Award for Doctoral Candidates from the National Science and Engineering Research Council (NSERC)

(2008). New Brunswick Teachers Federation (NBTA) Professional Development Research Award

(2008). International Scholarship from National Association for Research in Science Teaching (NARST)